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THE NATURE OF REPLACEMENT.[1]

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SUMMARY OF PREVIOUS VIEWS.

The difficulty of an adequate explanation of the geologic process known as metasomatism or replacement has long been recognized. A crystal of cuprite converted to native copper; cubes of pyrite developing in shale; grains of galena introduced into crystalline limestone and taking the place of calcite; zoisite almost filling a once continuous crystal of labradorite; all such phenomena are grouped under the general heading of metasomatism.

In the case of pseudomorphs of free crystals there could be little room for doubt that a chemical transformation had actually taken place. Where the new mineral appeared with perfect crystal form in the solid mass of the older substance, opinions differed widely as to the nature of the process.

The prevailing view in the earlier days of the science of ore deposits was that the growing crystal had by means of its "force of crystallization" pushed apart the surrounding mass. It was shown that clear crystals of ferrous sulphate would develop in a mixture of its solution with some neutral powder, and the occurrence of clear gypsum crystals in clay was justly taken as a proof that such a force existed. On the other hand were cited

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instances where the growing crystal has failed to exert this mechanical force, as in the well-known calcite crystals in the sand of the Fontainebleau, which include so much foreign material as to appear like crystals of sand. Von Groddeck thirty-five years ago declared that the development of a complete crystal in a rigid mass was not possible. Apparent exceptions, such as magnetite crystals in chloritic schist, he considered due to crystallization in a rock which has been softened by metamorphic agencies. Another explanation frequently applied to replacements in crystal form in solid rock was that the new mineral had filled solution cavities.

Those approaching the subject from the standpoint of petrography have generally assumed that the action in replacement is a chemical interchange "molecule for molecule." Mr. G. F. Becker[1] for instance states that:

"The theory of the substitution of ore for rock is to be accepted only when there is definite evidence of pseudomorphic, molecular replacement."

Other writers have not followed this strict definition. S. F. Emmons,[2] for instance, has defined metasomatism as follows:

"By metasomatic exchange is meant an interchange of substance without necessarily involving, as does pseudomorphism, the preservation of the original form of the substance replaced, or even of its original volume."

A second definition, based on the consideration that practically simultaneous solution and deposition could certainly be proved for many cases, where the exact proof of chemical-molecular replacement could not be furnished, is given by Mr. Emmons[3] as follows:

"By metasomatic interchange I understand an interchange of substances, but not necessarily molecule by molecule, in such a manner as to preserve the original structure, form, or volume of the substance replaced."

[1] *Trans. Am. Inst. Min. Eng.*, Vol. 23, 1893, in discussion of Posepny's paper. See also "Genesis of Ore Deposits," *Am. Inst. Min. Eng.*, 1901, p. 204.

[2] Mon. U. S. Geol. Survey, Vol. 12, p. 565.

[3] "The Genesis of Certain Ore-deposits," *Trans. Am. Inst. Min. Eng.*, Vol. 15, 1886, p. 128.

In 1900, W. Lindgren wrote as follows:[1]

"The fundamental difficulty is that the final result does not always indicate the particular pseudomorphic process which has preceded. Mechanical deposition, for instance, may follow so closely after dissolution, that the two processes really appear as one. It may also be said that molecular replacement is difficult to prove, as molecular processes cannot be followed with the microscope; and this is, in a sense, true. We may assert, however, that with the highest magnifying powers, we are able to follow the transformation of quartz, for instance, into sericite, or into calcite or into siderite, without finding the slightest indication of an intermediate stage of open space. The fibres and blades of sericite project into the quartz without the slightest break in the contact; the rhombohedrons of siderite develop in quartzite, their crystal faces cutting across the grains without interstices. Perfect tourmaline prisms develop in feldspar grains, and sharp cubes of pyrite in primary granitic quartz.

"In cases of complete molecular replacement, such as galena after calcite, the replacing mineral was probably present in the solution, partly dissociated or ionized. The solution of a certain quantity of the original mineral caused the separation of a corresponding quantity of the ions of the replacing substance, according to physico-chemical laws. If carried out on these lines, the process is necessarily molecular and chemical. Where there were two solutions—one dissolving, the other depositing—and where a certain time intervened, the process is a mechanical one and should not, I think, be considered metasomatic. In many cases the distinction may be very difficult to draw."

Van Hise[2] assumes that alterations are ordinarily attended by changes in volume, and gives an extended list of the chemical formulas involved. From the formula expressing the change he calculates the increase or decrease in volume on the following basis:

"The volume of the original compound is to the volume of the compound produced directly as their molecular weights and indirectly as their specific gravities."

Apparently Van Hise considers this principle applicable to all metasomatic changes that take place in rocks.

[1] Lindgren, W., "Metasomatic Processes in Fissure-veins," *Trans. Am. Inst. Min. Eng.*, Vol. 30, 1900, p. 584 (1901).

[2] "Metamorphism," Mon. U. S. Geol. Survey, Vol. 47, 1904, p. 209.

In 1911 J. D. Irving[1] published a paper on "Replacement Ore Bodies," in which he discussed the changes in volume during replacement. He recognized that increase in volume of the resulting ore, which would find expression in optical anomalies, has never yet been detected. A decrease in volume often takes place, according to Irving, and may find expression in rock porosity consequent upon the substitution of dense minerals for those of less density. If the molecular volumes of the minerals which are often substituted for calcareous rocks be examined and compared with those of the component minerals of the replaced material, it will be found that the molecular volumes of the new minerals are sometimes smaller and sometimes larger than those of the original rock. Irving says:

"In cases where the molecular volume of the new mineral is a little less than that of the mineral replaced, it is obvious that if an equation be assumed for replacement involving only the substitution of one molecule of new mineral for one molecule of original rock, a slight decrease of volume would result. It frequently happens, however, that the replacing mineral shows a much less or much greater decrease in volume (as shown by the volume vugs or cavities in the replacing mineral) than is called for by this difference, and it is quite evident that the equation assumed for the change may involve different numbers of molecules on its two sides. This is especially evident when a mineral like quartz replaces limestone, and the vugs or cavities left in the resulting material are in greater abundance than the difference in molecular volume would seem to justify. Again, it is frequently the case that the molecular volume such as that of wolframite is greater than that of the original mineral, and yet a very marked decrease in total volume has occurred. This is seen in wolframite deposits of the Black Hills, South Dakota, which replace limestone. It is impossible to calculate this change exactly from analyses, unless some one element has persisted unchanged in the process, which does not often happen. The observed facts, however, whatever may be the theoretically calculated change, show that in nearly all siliceous replacements and in by far the greater number of metallic replacements there has been an appreciable and often very marked decrease in the volume of the rock. This finds

[1] "Some Features of Replacement of Ore-bodies, etc.," *Jour. Can. Min. Inst.*, 14, 1911, pp. 395–471. *Trans. Am. Inst. Min. Eng.*, 1912. Econ. Geology, vol 6, 1911, pp. 527–561; 619–669, "In Types of Ore Deposits," San Francisco and London, 1911, pp. 220–298.

expression in widely distributed cavities in the ore into which crystals of the latest formed ore minerals project. These cavities are usually without regular form or orientation, having all possible forms and being set at any angle to the original rock structure and to each other. They are frequently of extremely intricate form, being almost labyrinthine in their complexity. Such a reduction in volume is further borne out by the fact that in most cases the total space occupied by the new material is of exactly the same size as before alteration. That is, the rock mass itself has not been condensed into a smaller space. Thus in Leadville the rock structures, stratification, and porphyry limestone contacts are not at all disturbed during mineralization. Likewise in the siliceous ores of the Black Hills the strata run directly through the ore, and where two unmineralized layers run through the mineral mass without silicification the shale bands are no nearer together nor farther apart than before the replacement."

CLASSES OF REPLACEMENT.

Irving's discussion is of great value because he recognizes the difficulties of the subject and attempts to elucidate them by careful descriptions of actual occurrences. Stimulated by this work I have attempted to view the subject from a different aspect, and have been led to results differing somewhat from those of Irving.

In the first place, I believe that in discussing the changes which take place when one mineral is transformed into another it is necessary to distinguish between (1) reactions in open space; (2) reactions in yielding material, and (3) reactions within rigid rocks. In the first case no restraining influences oppose changes of volume; in the third case the newly developing mineral is surrounded on all sides by unyielding material and is forced to make room for itself by solution of the host mineral. I do not believe this difference has been realized. In the first case volume changes are in general inevitable; in the second case they seldom take place.

Replacement in Free Space.—If the proper volumes of two substances, say calcite and quartz, be melted together, wollastonite will crystallize from the melt and the result will be a reduction of volume as compared to the volumes of the original minerals. Similarly, if a crystal of cuprite in a vug is altered to

a pseudomorph consisting of native copper there will be a reduction of volume, expressed by a porous texture or sunken faces of the crystal. Practically all of the pseudomorphs produced by direct alteration are of this kind. Blum[1] in describing, for instance, a pseudomorph of argenite after proustite emphasizes the lack of luster and the loss of sharpness of the edges. The surface shows many small projecting cubes of argentite, which form a drusy aggregate. Antimony has been wholly removed, sulphur only in part, while the original amount of silver remains. G. Bishof[2] also emphasizes that by far the greater number of pseudomorphs present a porous structure.

In some cases, for instance in the pseudomorphs of limonite after pyrite, the replacing mineral retains almost exactly the form of the original, because the substances removed are more or less exactly balanced by those added.

The well-known pseudomorphs of smithsonite after calcite are usually spongy or hollow, indicating a considerable contraction of mass volume although the pseudomorphs as a whole may be as large as the original crystal. The specific gravity of calcite is 2.71 and that of smithsonite 4.30. One cubic centimeter of calcite contains 1,192 milligrams CO_2 and 1,518 milligrams CaO, One cubic centimeter of zinc carbonate contains on the other hand 1,514 milligrams CO_2 and 2,787 milligrams ZnO. If the replacement therefore can be expressed by the reaction $CaCO_3 + ZnSO_4 = CaSO_4 + ZnCO_3$, and if no more CO_2 is available, the volume of the resulting smithsonite must be considerably less than that of the calcite. Thus loss results in porosity.

There are, of course, other kinds of pseudomorphs which have not been considered in this discussion. They include those formed by two distinct processes of solution and deposition, either by the solution of the original crystal and subsequent filling of the space, or by the covering of a crystal by material deposited from a solution and subsequent removal of the original crystal.

[1] Blum, J. H., "Die Pseudomorphosen des Mineralreiches," Stuttgart, 1843.
[2] "Elements of Chemical and Physical Geology," Vol. 1, 1854, London, p. 39.

Replacement in Rigid Rocks.—Replacements in rigid rocks include a variety of highly important geologic processes. The alteration of all kinds of rocks by common hydro-metamorphism under static conditions as well as the development of crystalline schists under stress, involve as the most essential feature transformation of the primary minerals by replacement. Recrystallization of rocks in or near ore deposits and the growth in them of metallic sulphides are likewise phases of the processes of replacement or metasomatism. For example, chlorite, kaolin, sericite, carbonates, epidote and pyrite easily develop in the feldspars and ferromagnesian silicates of rocks. Each foil of chlorite or sericite develops at the expense of old substance without leaving spaces that can be observed with the microscope. Each pyrite crystal fits closely into the host mineral occupying exactly the space needed for the new crystal.

If the old mineral appeared in crystal form, this may be preserved by the new mineral, the result being a real pseudomorph, which usually is an aggregate of small grains. Commonly, however, the new aggregates spread beyond the outlines of the primary mineral and the outlines of the old grain or crystal can then no longer be perceived. In partial replacements the secondary mineral may be a single individual, with or without crystal form, which is contained within the mass of the primary grain or crystal. Sometimes one new crystal will occupy parts of two adjacent grains and these two may belong to the same or different mineral species. Frequently, indeed, it happens that an aggregate of minerals or *a rock* is replaced by a single new mineral. Pyrite or arsenopyrite often develops as large perfect crystals in fine-grained compact argillites composed of quartz, kaolin, sericite, etc.; it cannot be said that this happened while the rocks were soft, for in the cases in mind the replacement occurred after the hardening and metamorphism of the rock, at a time when it was exposed to solutions producing ore deposits in adjacent fissures. The development of crystals of staurolite and andalusite in argillaceous rocks under the influence of contact metamorphism is another example of the replacement of a rock. The replacing mineral is in some cases entirely free from inclusions. In other

cases, as in many staurolite crystals, it contains abundant particles of the primary rock which escaped the replacing influence.

The replacement is effected by liquid or gaseous solutions which penetrated the pores, cracks, or fissures of the rock. If, as often happens, a perfect cube of pyrite is embedded in a grain of quartz or feldspar, close examination will rarely fail to discover a minute veinlet or fissure leading up to the crystal and through which the solutions found their way. At high temperature many fine-grained rocks seem to be comparatively easily permeable by solutions.

Replacement indicates that the primary minerals have been subjected to conditions under which they were unstable. The solutions penetrating them contain the elements of minerals which are stable under these conditions. When these solutions, contained as films between the grains or in little fissures become supersaturated by the effects of adsorption, solution of the unstable and precipitation of the stable mineral will follow.

Recrystallization by replacement usually begins from a great number of centers and spreads through the rock. Each mineral developing in another may be called a *metasome,* and when it assumes crystalline form a *metacryst.*[1]

In metasomatic rocks there is no definite succession of minerals as in igneous rocks and the metacrysts derive their prominence not from being earlier products of crystallization but from the fact of their superior tendency to crystallization.

The general experience of geologists is that the partially or wholly replaced rocks are compact and firm, never porous or cellular. Any epidotized diabase, amphibolite schist, or gneissic rock will illustrate this. F. Becke[2] among others emphasizes this fact.

[1] This term was originally proposed by A. C. Lane (*Bull. Geol. Soc. Am.,* Vol. 14, p. 369, 1903), who, however, did not enter into a discussion of the phenomena of replacement. Several years ago F. Becke (*loc. cit.*) proposed the term "idioblast" for metacryst and "xenoblast" for metasome, but thus far these terms, not particularly euphonious in English, have failed to find general acceptance in this country.

[2] "Ueber Mineralbestand und Struktur der Kristallinen Schiefer," Congrés geol. intern. Compte Rendu, 9th Session, Vienna, 1903, pp. 553–570.

In crystalline schists formed at considerable depths there should theoretically appear a contraction of volume inasmuch as lighter minerals have been replaced by denser, but no conclusive testimony is available on this point.

On the whole similar relations hold for metasomatic rocks near ore deposits or forming part of ore deposits. Evidence showing expansion of volume has not been adduced, as remarked by Irving (p. 524). I am unable to accept Irving's statement that in the majority of cases there has been a considerable decrease in the volume of the rock. If contraction of volume has taken place it has found expression in porosity rather than in actual contraction of the previous volume of the rock.

Microscopic examination of rocks and ores in which replacement has occurred shows clearly that exactly that amount of primary mineral is dissolved which is necessary for the reception of the secondary mineral. In other words, the volume of the replacing mineral equals the volume of the mineral replaced. This law of equal volumes is illustrated by the figures in many reports dealing with this subject. In my paper on the "Metasomatic Processes in Fissure Veins" one example is shown in the incipient silicification of limestone from Aspen, Colorado; each of the little quartz crystals, many of which are perfectly formed, lies completely embedded in the fine-grained limestone mass, and occupies exactly the space necessary for its reception. When the process went on with more than usual rapidity small particles of calcite were enclosed in the quartz and were thus cut off from further action by the solution.

The figure of fluorite replacing limestone, given in the paper mentioned, and that which Irving presents, of barite replacing the rock,[1] seem to show conclusively that the barite and the fluorite have precisely the same volume as the limestone removed. A similar statement applies to the siderite which has formed in the quartz grains of the quartzitic schists of the Coeur d'Alene region, and to the tourmaline often forming as needles or prisms in feldspar and quartz. It is necessary, of course, that it should be

[1] See J. D. Irving, *Jour. Can. Min. Inst.*, Vol. 14, 1900, Figs. 19, 20, 21, 22, 23 and 24.

definitely known that the minerals mentioned are introduced later than the surrounding material. In the cases mentioned this knowledge is assured.

The replacement of calcite by galena is one of the transformations which early attracted attention in the study of metasomatic processes. Thin sections of galena in process of replacing crystalline limestone and other calcareous rocks show plainly that here too the space removed has been simultaneously filled. The proof of this is, of course, only conclusive when the galena is in sharp crystals. This, however, is often the case, and is illustrated by almost any specimen of ore from southeastern Missouri. It is also shown by Buckley's[1] illustration in his report on these deposits.

The replacement of free calcite crystals by smithsonite or zinc carbonate with contraction of volume was mentioned above (p. 526). Replacements of limestone by smithsonite within the rigid rocks are quite common, and in this case the mineral often reproduces exactly the texture of the original rock, even to the most minute details; the resulting secondary zinc mineral is compact and at least not more porous than the original limestone. If this replacement were effected according to a chemical equation, be it by substitution of zinc for calcium in carbonate or by interchange of zinc sulphate and calcium carbonate (p. 526), a reduction in volume should necessarily be expected. It does not take place provided the metasomatic action goes on within the mass of the rock itself.

While, therefore, replacement is probably in a way a molecular process because it proceeds by practically simultaneous solution and deposition, yet it proceeds independently of the molecular weight, molecular volume and the specific gravities of the minerals participating.

One consequence of this is that all of the equations written to illustrate replacements fail to represent the correct course of the process. The equations represent replacement by equal weights, whereas it actually takes place by equal volumes. Replacement

[1] E. R. Buckley, "Geology of the Disseminated Lead Deposits," *Missouri Bur. Geol. and Mines*, Vol. 9, Pt. 1, Plate 34.

is therefore not molecular in the sense that for every molecule of substance removed a single molecule or a definite number of molecules of some other substance is deposited.

The preservation of the texture of the original rock is quite common in replacements and is another proof that the process follows the law of equal volumes. Delicately sculptured shells are reproduced in the minutest details in silicified limestones and the same has even been observed where the rock is replaced by garnet in zones of contact metamorphism.[1] The illustrations in Irving's paper[2] show that the rhombohedral crystals of dolomite are faithfully preserved in the silicified rock and that the brecciated structure is perfectly retained. Judging from these illustrations it does not seem possible that important change of volume could have taken place without resulting in distortion of structural and textural lines. Both S. F. Emmons and J. D. Irving describe the replacement of limestone by compact sulphide ore at Leadville, and state that the ore preserves so minutely the cracks, joints, and other structural features of the limestone that when covered by a thin layer of mine dust which conceals the metallic gleam of the sulphides the ore has the appearance of limestone.

Replacement by equal volume demands the nicest balance between solution and precipitation and takes place when the rock is permeated by stagnant or slowly moving solvents. Where the solvent carries foreign supplies of solute the process becomes more complicated. The precipitates are in part made up from the rock material and in part from the additional substance; the moving solvents carry away a certain part of the rock substance that room may be made for the incoming material. When the solvents penetrate the rock rapidly and are dilute a condition may arise in which the law of equal volumes no longer holds. This happens for instance near the surface, in the zone of weathering, where the rocks finally become porous and disintegrate.

Sometimes similar conditions may arise in case of rocks pene-

[1] Lindgren, W., Prof. Paper U. S. Geol. Survey No. 68, p. 294

[2] *Loc. cit., Jour. Can. Min. Inst.*, Fig. 8, Plate 6.

trated by rapidly moving solutions as in the formation of certain replacement ore bodies.

Irving describes the drusy cavities common in the silicified dolomite, constituting the "refractory" gold ores of the Black Hills of South Dakota, and assumes that they express the measure of reduction of volume during the change from dolomite to fine-grained quartz. It is, however, scarcely conceivable that a reduction in volume, due to silicification, should be represented by such relatively large and irregularly dispersed cavities, the volumes of which apparently bear no constant relation to the volume of the rock. If the volume is reduced by this process the shrinkage should be distributed more uniformly and should result in a general porous texture, such as is found in many pseudomorphs. These druses are probably caused by local changes of composition of the replacing liquid during rapid progress of metasomatic action. Dolomite was dissolved at places where the solution did not carry enough silica to effect a replacement.

POROSITY.

Rocks subject to static and dynamic metamorphism show, as far as known, little evidence of porosity. Altered wall rocks of metalliferous veins which have been subjected to sericitization are sometimes fully as compact as the original rock—a diorite or a diabase for instance—but in some cases the sericitized rock does show porosity, which may amount to two or three per cent. Sericitization involves the replacement of a compact primary mineral by a felt of foils and fibers, that is, the replacement proceeds from an extremely large number of centers. While no cavities are visible under the microscope, it is probable that the slight, sub-microscopic interstices which always must exist between the replaced and the replacing mineral are sufficient to account for this porosity.

FORCE OF CRYSTALLIZATION.[1]

The force of crystallization has not been considered in the

[1] For literature on this subject see K. Andrée, "Die geologische Bedeutung des Wachstumsdruckes Kristallisierender Substanzen." *Geologische Rundschau*, Bd. 3, fasc. 1, 1912.

preceding discussion, and it is believed that in a rigid medium like quartz and feldspar it is not sufficient to make room for the new crystal. The general absence of fracturing or breaking of the host mineral is evidence enough; even optical anomalies and undulous extinction are uncommon around crystals developing in comparatively rigid minerals.

Much is occasionally claimed for this "force of crystallization" but while it is undoubtedly an actuality, as for instance shown by the experiments of Becker and Day, it is not likely that it is capable of widening of fissures in solid rocks in depth, nor that crystals can develop against a strong counter-pressure without showing a flattening perpendicularly to that pressure. In metasomatic processes the resulting minerals most commonly are of irregular outlines; only certain species show such a strong tendency to crystallization that the crystal form asserts itself in rigid material. Such minerals are pyrite, arsenopyrite, tourmaline, rutile, and garnet.

The metasomatic crystals are usually well developed and of normal shape. Simple forms predominate, but the faces parallel to the cleavage do not necessarily prevail as stated by F. Becke. Fluorite, for instance, is often found in cubical crystals and domes and prisms are shown in metasomatic barite crystals. Where well developed crystals form it is evident that the force of crystallization comes into play, though not to the extent of breaking the host mineral. A pressure is exerted against the host mineral, and it differs in intensity with the crystallographic direction. According to the principle of Riecke solution proceeds most actively at points of greatest pressure and it is this difference in the rate of solution that permits the development of crystal faces. According to the conception of Curie and Becke those crystal faces are most easily produced in which the molecules are most closely massed.

CRYSTALLIZATION IN YIELDING SUBSTANCES.

In soft shales and foliated schists consisting largely of chlorite or biotite, the stresses produced by crystallization may become of

direct importance. Crystals of pyrite, magnetite, garnet, etc., developing in such media are often surrounded by bulging lamellæ of mica or chlorite or curved lines of stratification. In such cases the law of equal volumes does not hold and the forces of replacement and crystallization have probably coöperated. Where the material is thoroughly softened and clayey the development may be almost entirely governed by the laws of crystallization in free space. Upon close examination it will usually be found however, that the displacement measured by the curving of the structural lines around the crystal is by no means as large as the size of the crystal would require. An illustration of this is shown in Buckley's[1] figures of cubes of galena in dolomitic shale. There are also many cases in which the replacing mineral cuts squarely across the laminæ of the shale or slate; one of these is illustrated by Irving.[2]

CONCLUSIONS.

The transformation of one mineral into another of different chemical composition, effected by practically simultaneous solution and precipitation, is called replacement or metasomatism. It is necessary to distinguish between (1) reactions in open space where no restraining influences oppose a change of volume or where the force of crystallization can easily overcome the restraining pressure, and (2) reactions in rigid rocks where the new mineral is forced to make room for itself by solution of the host mineral; in this case the volume of the replacing mineral equals that of the mineral replaced; the force of crystallization is of little or no direct influence but the pressure exerted probably promotes solution. The chemical equations written to express such replacements are of little value because they give relations by weight instead of relations by volume. Such replacement proceeds independently of molecular weight, molecular volume and specific gravity. It does not take place "molecule for molecule" nor by a given proportion between the molecules dissolved and precipitated. At the same time it is molecular or at least sub-

[1] E. R. Buckley, *l. c.*

[2] *Jour. Can. Min. Inst.*, Vol. 14, 1911, Fig. 26.

microscopic in the sense that complex chemical reactions constantly take place in the contact films of solutions; the process goes on in one operation, solution and precipitation following so closely that no spaces of solution are visible under the microscope. Structure and texture are often faithfully preserved. If replacement proceeds from an extremely large number of points in a mineral, with the development of fine-grained substance, increased porosity may result from the aggregate of minute solution ducts.

Replacement by equal volume takes place in most perfect form when the rock is permeated by stagnant or slowly moving solutions. Replacements in mineral deposits are sometimes caused by rapidly moving solutions and then the equilibrium may be disturbed; solution may be more active than deposition; drusy structures may then result by local deficiency of the solutions in the substances precipitated.

TEMPERATURE IN OIL REGIONS.[1]

DR. HANS V. HÖFER.

We know comparatively little about the temperature of oil-producing strata; and in many regions there is not one known determination of the temperature of the oil. It is desirable that geothermic measurements of this sort be made during the drilling of the well.

At gas wells near Baku, Abich has found the temperature of the discharged gases to be 20°.25 Celsius, which corresponds to a normal downward increase in the temperature of the earth's crust, but such measurements in gas have little value, because the gas has been cooled by expansion, and they do not give the true temperature in the gas horizon. This principle (adiabatic cooling) plays a strong rôle also in the case of crude oils rich in gas, so that, scientifically, only those temperature determinations have value which are made in flowing oil as free of gas as possible, and preferably at the point of issue from the oil-sand into the well. At least, in such observations, the content of gas-bubbles must always be noted, if only crudely by such expressions as "very rich in gas," "rich," "poor," etc.

To ascertain the temperatures of the individual strata and oil horizons of a region is a hard task. Daubrée[2] visited the "oil mines" of Pechelbronn, Elsass, in 1853 (discrepancy in date with reference—C. W. W.) and measured a temperature of 13.7 degrees Celsius in a "spring" 70 meters deep. Assuming a day temperature of 10° C., he calculated the geothermic gradient, that is the depth in meters for 1 degree Celsius rise in temperature, to be 20 meters. Later,[3] in the same oil region of Elsass, he measured the temperature in four drilled wells, arriving at the following figures:

[1] Free translation by C. W. Washburne of a separate from the "Organ des Vereines der Bohrtechniker," No. 23, Jahrgang XVIII., Vienna, 1911.

[2] "Descript. géol. du Bas-Rhin," 1852, p. 360.

[3] *Compt. rend.*, Vol. 117, p. 265, 1893.

Place.	Depth (Meters):	Geothermic Gradient (Meters).
Sulz u. d. Wald	178	12.7
Hagenau	305	12.2
Hagenau	620	8.2
Kutzenhausen	140	7.0

These gradients are unusually small. Daubrée, after referring to the regular and flat stratification of the Tertiary beds, remarked:

"Such an anomaly is all the more interesting, since it seems to have its ground in the same source as the presence of the oil, that is, in the especially strong influence (chemical or other) of the processes of the inner part of the earth."

Daubrée gives the measurements in the well at Sulz u. d. Wald (according to L. v. Werveke in Oberstritten) as follows:

Depth in Meters.		Temperature.		Geothermic Gradient (Meters).
Depth.	Difference.	Temp.	Difference.	
		°C.		
305		47.5		
	25		5.0	5.0
330		52.5		
	30		1.2	15.0
360		53.7		
	40		3.8	10.53
400		57.5		
	20		1.2	16.6
420		58.7		
	60		0.	∞
480		58.7		
	30		1.3	23.08
510		60.0		
	30		−0.6	− 0.50
540		59.4		
	40		0.	∞
580		59.4		
	20		1.2	16.6
600		60.6		
	20		0.	∞
620		60.6		

The heat gradients calculated from Daubrée's figures show much variation, which is too large, especially when one considers the great authority of Daubrée, to be assigned to errors of observation. There is a small geothermic gradient all the way down to 420 m.; this may be computed from the measurements

at 305 m. and 420 m. to average 10.27 m.; the average gradient from 305 to 360 is 8.87 m., and from 305 to 400 it is 9.5 m. per degree Celsius. Here there must be a local source of heat, probably a bituminous rock, but unfortunately Daubrée gives no stratigraphic section. Below 420 m. to 480 m. the temperature remains constant, then increases down to 510 m., but very slowly, as the normal gradient (33 to 35 m.) indicates, where another local source of heat may be inferred, below which the gradient remains contant to 620 m.

L. van Werveke[1] publishes the following observations made at Oberkutzenhausen, in the Elsass oil fields:

Well No. 1.			Well No. 2.		
Depth (Meters).	Temp. (Celsius).	Geothermic Gradient (Meters).	Depth (Meters).	Temp. (Celsius).	Geothermic Gradient (Meters).
239	18	11.87	305	30	12.22
509	41		415	39	12.62
			516	47	

Hence, also in this neighborhood the geothermic gradients are very small. Other temperature determinations in well No. 1 are recorded by L. v. Werveke:

Depth.	Gradient.
236 to 275 m.	7.8
275 to 281 m.	1.5
281 to 334 m.	6.1
387 to 509 m.	24.4

The last results accord with Daubrée's measurements, in showing a larger gradient in the lower strata than in those above. Here there must have been a local source of heat (in the upper strata) since the small gradients can not be due to the general warmth of the earth. We can assume that the source of this heat is the bituminous strata which were passed through in drilling the well. In well No. 1 a productive horizon was struck at 335.6 m., where the geothermic gradient fell to 6.1 m.

I am indebted to the royal Bergrevieramt of Elsass (Strassburg) for measurements which were made in the Constant field

[1] Engler-Höfer, "Das Erdöl," Vol. II., p. 225, 1909.

in Hagenaur Wald, at depths of 576.4 and 618.7 meters.[1] The ten observed temperatures fluctuate irregularly between 47 and 49 degrees Réaumur, with an average of 47.7 degrees Réaumur (= 59°.6 C.), for a mean depth of 597.5 m. The temperature of this place was taken to be 10° C. by Daubrée and Werveke; hence, the calculated gradient of underground temperature is 12.04 m. Traces of oil, gray and black marl, and clay were encountered in the well.

Max Mühlberg has accomplished temperature measurements in wells in Mexico and Borneo oil fields. They are published in an excellent study, made in association with Professor Johann Königsberger,[2] from them the following observations are borrowed:

Place.	Geothermic Gradient.	Depth (Meters).	Author.	Remarks.
Russia				
Apscheron	28.4	300–700	Golubjatnikow	Mean of oil temperatures in 170 wells.[1]
Berekei.....	23.0	ca. 1,000	Kalicky	"Paraffin-free oil."
Mexico				
Veracruz *A*.....	22.9	530	Mühlberg	In asphaltic oil.
Veracruz *B*.....	26.7	694	"	In a good oil layer.
Veracruz *C*.....	27.0	423	"	Upper half of the oil-producing bed.
Veracruz *D*.....	28.3	660	"	
Borneo				
Samarinda *A* ...	20.4	387	Mühlberg	Heavy oil and paraffin-oil; lignite.
Samarinda *B* ...	26.0	675	"	Little oil; lignite.
Samarinda *C* ...	20.4	471	"	Paraffin-oil; lignite.
Samarinda *D* ...	23.6	574	"	Dry well (*i. e.*, no oil); lignite.
Samarinda *E* ...	18.5	296	"	Much oil; lignite.
Japan				
Echigo oil field .	20.0	—	G. Kobaishi	Oil and gas.
California				
Santa Maria oil field.....	23.0	1,097	(R. Arnold and R. Anderson)	Oil.

[1] "Ueber Messungen der geothermischer Tiefenstufe, etc.," *Neues Jahrb. für Min. Geol.*, Beilage, Vol. 31, p. 107, 1911.

[2] For reasons pointed out on the first page of this article, temperature measurements in outflowing oil have only slight value. The geothermic gradient of Apscheron and Berekei may be increased through the cooling influence of the neighboring Caspian Sea.—Höfer.

The results of the preceding measurements demonstrate beyond doubt that an abnormally small geothermic gradient prevails in oil regions, smaller than in fields of bituminous or anthracite coal. For the Elsass oil region this gradient is approximately 12 meters. A recent volcanic addition to the underground temperature is there excluded, as is also any heating influence of geodynamic energy. As in this region, only the occurrence of the bitumens appears to be peculiar, so it is permissible to regard this as the source of the heat which conditions the low geothermic gradient. In this connection I may add that I,[1] in opposition to Branca, have accounted for the longest known small geothermic gradient (11.1 m.) in the perforation at Neuffen (Würtemberg) by the presence of the bituminous Liassic shale, and I now find a new confirmation in the observations in Elsass.

Whether the warmth here accumulated has remained from the time of formation of the bitumen,[2] or whether it is derived from an extensive transformation[3] of the bitumen,[2] as seems more probable, remains undecided for the present.

The preceding observations do not warrant further conclusions. Many exact geothermic measurements must be made and must be compared with accurate stratigraphic sections of each well. The results of this investigation certainly will have high scientific importance. They may also become of especial practical value if the researches indicate that the temperature rises sharply in the neighborhood of an oil-deposit, for example in the case of a deep boring about which there is question of the advisability of drilling deeper.

Considering the double value of these geothermic investigations in oil regions, it is to be hoped that they will be undertaken soon, and in many places. To this end an especial appeal is made to geological surveys. Moreover, in recent times the oil profession

[1] "Oesterr. Zeitschrift f. Berg-u. Huttenwesen," Vol. 49, p. 249, 1901.
[2] Hydrocarbons.—C. W. W.
[3] Probably means decomposition.—C. W. W.

has turned to applied science in a most happy way, and it is controlled by high intelligence and great capital, so that we may hope that the field managers also will enter the service of geothermics, in which the standard was set decades ago by the never-to-be-forgotten Köbrich.

NIGERIAN TIN; ITS OCCURRENCE AND ORIGIN.

J. D. Falconer.

The tinfields of northern Nigeria lie mainly in the heart of the Protectorate, on the summit and round the margins of the great central plateau.[1] The tinstone occurs both in placers and in lodes, but up to the present practically all the tinstone which has been exported has been taken from the alluvial deposits. The stream tin had been worked and smelted on a small scale by the natives of Lirue-n-Kano for a lengthy period before the British occupation of Nigeria in 1900, but all that was known of its point of origin was that it was produced somewhere in the pagan and at that time hostile country of Bauchi. It was not indeed until 1902 that a definite effort was made by the Niger Co. to locate the tinstone in Bauchi province, and in 1904 the first mining camp was established on the banks of the Delimi river on the site of what is now Naraguta, the center of the mining industry of western Bauchi. The alluvial tin was thus the first to be discovered, but more recently careful search in the surrounding country has proved the presence of lodes in the vicinity of the placers. Little or no scientific study of these lodes has yet been carried out, but so far as investigation has gone, there would appear to be some slight difference in mineral content between the placers and the lodes, sufficient to suggest the conclusion that the original habitat of the placer tin has not yet been definitely ascertained.

Like most placers the tin-bearing gravels of northern Nigeria are believed to be of comparatively recent age and to date from a period immediately preceding the establishment of the present river system. They are distributed over an area of about 9,000 square miles, mainly in western Bauchi, but extending also into

[1] V. Geology and Geography of Northern Nigeria. J. D. Falconer. Macmillan Co., 1911.

the adjoining provinces of Zaria and Nassarawa. The richer deposits are found in the valleys of western Bauchi where the tinstone has been naturally concentrated by the present streams. Water is available for hand work and for sluicing during the greater part of the year and the ore can be easily and abundantly won from the gravels by the simplest methods. It is in such places only that the work of development has hitherto been attempted, and full credit is due to the Niger Co. for being the first to demonstrate the possibility of working these deposits at a satisfactory profit in the face of many difficulties. Native labor is comparatively scarce, the cost of white supervision is high, and inland transport charges are particularly excessive. The Bauchi tinfields lie at a distance of 150 miles from Loko on the river Benue, the nearest accessible point for steamers and barges, and hitherto the tinstone has had to be carried to the river by porters travelling about 15 miles a day with the ore on their heads in bags of about 60 lbs. weight. It was this difficulty of transport, more than any other, which led in the first instance to the search for and the exploitation of the richer areas only. The poorer alluvials were everywhere neglected and little time was spent in the search for lodes. The absence of railways and even of roads and bridges rendered almost impossible the introduction of heavy machinery by which alone the poorer ground and the lodes could be profitably worked. In spite of all these disadvantages, however, several companies, following the example of the Niger Co., have been able to place quantities of Nigerian tin upon the home market and secure from it a highly satisfactory return. The difficulties of labor and supervision still remain, but the completion of the Baro-Kano railway and of the branch line, now in course of construction, from Zaria into the heart of the tin area will entirely revolutionize the conditions of transport previously existing and put the tinfields into direct communication with the port of Lagos. There is now, therefore, every possibility of the poorer alluvials and of the lodes being easily and profitably worked in the immediate future, and the improved prospects of the industry are now attracting to the country large numbers of prospectors and concessionaires, while a large amount of capital

has already been invested in various enterprises of greater or less stability.

With the tinstone in the richest alluvials, there occur in considerable abundance rolled fragments of white and yellow topaz and small pyramidal and octohedral crystals of brown zircon. These two minerals indeed might almost be said to play the part of indicators. Along with them however there occur also in the concentrates small quantities of magnetite, ilmenite, rutile, garnet, monazite, and an occasional color of gold, but there is little difficulty in obtaining concentrates sufficiently pure to assay 70 per cent. metallic tin. The tinstone itself varies in color from black to ruby or pale yellow and assays about 75 per cent. metallic tin. This Nigerian product is said to be one of the best tins imported into Europe and to command a price equal to, if not better than, that of tin from the Straits.

The alluvial deposits are found in close association with extensive masses of alkaline granite which have been injected into the surrounding gneisses and schists, and it was early suggested that the tinstone of the gravels was probably derived from the granite, where it might occur either sporadically as a rock constituent or as stockworks on the margins of the igneous mass. It was not, however, until 1908 that the prospectors of the Niger Co. actually discovered tinstone in the granite, in the neighborhood of Naraguta, but on the summit of the plateau and in the heart of the intrusive mass. At this place the granite shows signs of later movement, of fracturing and fissuring along certain lines and of accompanying pneumatolytic action. The adjoining rock is chloritized and partially mineralized, while the fissures themselves are filled with ore-bearing pegmatite and veinstuff. The tinstone is associated with various sulphide ores, pyrites, chalcopyrite, tetrahedrite, blende and galena, of all of which little or no trace is to be found in the alluvial deposits. On the other hand topaz and brown zircon appear to be absent from the lode formations yet discovered, and while they are probably also of pneumatolytic origin, their exact mode of occurrence in the granites still remains somewhat doubtful. There is indeed every possibility of lodes

and stockworks being yet discovered in the granites, of which tinstone and topaz will be the most conspicuous minerals.

The tinstone in Bauchi province, in and around the plateau and in the Lirue and Ningi Hills to the north, appears everywhere to be associated in this way with masses of uncrushed soda granite. The small quantities of tinstone that have been found in Yola province and on the Kameruns border are probably also of similar origin. Tinstone, however, is also in places found as a constituent of some of the pegmatite dykes which are everywhere abundant amongst the gneisses and schists. These dykes are frequently rich in tourmaline, but, curiously enough, the tourmaline pegmatites, so far as investigation has yet been made, do not carry tinstone. At Eri in Kabba province there are pegmatites in gneiss carrying quartz, muscovite and abundant cassiterite but no tourmaline, and it is probable that many others of similar character may yet be located.

A stanniferous lode four miles in length is reported to have been discovered on the property of the Anglo-Continental Mines Co. in the Jemaa district of Nassarawa province, but the available information concerning it is insufficient to allow of any definite conclusion being drawn as to whether it is a true fissure lode, a stockwork in granite, or a pegmatite dyke in granite or gneiss.

The tin-bearing and tourmaline-bearing pegmatites are very similar in structure and probably belong to the same general period of igneous activity as the larger masses of tourmaline and alkaline granite throughout the Protectorate. It seems probable that the tourmaline granites and pegmatites were formed during an early phase of this igneous period, while the emanations which gave rise to the metallic lodes and the stanniferous pegmatites were characteristic of an entirely distinct and later phase, posterior to the solidification of the larger masses of alkaline granite. It follows, therefore, that in Nigeria the presence of abundant tourmaline in granites and pegmatites is no safe indication of the presence of tinstone in the same neighborhood.

At present however the stanniferous gravels are of the most importance, and in view of their extensive distribution northern

Nigeria has already been claimed as one of the largest tin-producing areas in the world. The solution of the transport difficulty and the introduction of heavy machinery will naturally lead to the use of improved working methods. The winning of tin from the richer alluvials, which is at present a highly profitable business, will become more remunerative still, while the poorer alluvials will be made to yield quite a satisfactory return. The cost of native labor for calabashing and sluicing is now 6 d. per day, but when machinery is introduced it is believed that 30 men and one plant will be able to produce as much and even more tin than is now being obtained with 300 men. Needless to say, however, the life of an alluvial mining field is comparatively short and especially so if it is worked economically with machinery on a large scale. The permanency of the industry in Nigeria will therefore ultimately depend upon the discovery and development of the parent lodes of the placer tin and steady systematic search for such lodes should be carried out upon every opportunity. That they do occur in places has already been demonstrated and there is every reason to believe that their distribution will prove almost as wide as that of the gravels themselves.

THE GEOLOGIC AND STRUCTURAL RELATIONS AT SANTA RITA (CHINO), NEW MEXICO.[1]

SIDNEY PAIGE.

The following paper will present briefly the major geologic and structural features observed in the Santa Rita region while the writer was engaged in preparing a geologic map of the Silver City Quadrangle during the summer of 1910. The area about Santa Rita was not given such attention as it would naturally receive in the course of an exhaustive study for a monographic publication. Nevertheless, in the preparation of a geologic map on a scale of 2 miles to the inch (approximately) the major relations were of necessity determined. It is because of certain misapprehensions which have arisen regarding this interesting and economically important area that the following paper is presented. That the views herein expressed do not wholly agree with what has already been published[2] rests solely upon the fact that the writer was afforded more ample opportunities to pursue the investigation.

It is of interest to state briefly the views of Mr. Graton (to whom fell the lot of examining this area) as well as those of a number of other observers. Mr. Graton says:

"The most conspicuous quartzite is found in the heart of the developed area in the Santa Rita camp and immediately to west and south. What is regarded as the same quartzite is present in places along the west side of Hanover Creek and in the Hanover mine and is said to extend on the surface for some distance farther northwest, though this statement was not verified. The rock is rather fine grained, gritty, decidedly cemented by silica, and commonly almost white, though in places it is almost black owing to the presence of black iron ore in small grains.

[1] Published with the permission of the Director of the United States Geological Survey.

[2] Lindgren, Graton and Gordon, "Ore Deposits of New Mexico," Prof. Paper, U. S. Geol. Survey, No. 68, 1910.

The quartzite probably has a thickness of at least 200 feet; it occurs on the surface at the Romero mine and is present in a crosscut from the Santa Rita shaft 200 feet below; the intervening ground is inaccessible and it is not certain that the quartzite extends throughout that distance, as irregular intrusions of porphyry are numerous in the vicinity. The bottom of the quartzite is somewhere above the 300-foot level, for the rock is not seen at that depth. The quartzite along Hanover Creek underlies and apparently belongs at a lower horizon than the limestone; the quartzite at Romero Hill is believed to occupy a similar stratigraphic position and in the absence of any other known quartzite below the Carboniferous is regarded probably as Cambrian and the equivalent of the thick quartzite series at the base of the Silver City section, 15 miles to the west. This view is strengthened by the similar character of these rocks in the two regions.

"Near the Ivanhoe mine, in the southwest corner of the area, quartzite is found close to the limestone already mentioned as probably Mississippian, and though the actual relations of the two were not ascertained, it is believed that the quartzite overlies the limestone. Much of this quartzite is gray, of finer grain and less cemented by silica than the quartzite previously described; it is conglomeratic and cherty in places like that occurring between the Carboniferous and the Cretaceous in the Silver City section. Quartzite believed to be related to this occurs on the Pedro claim on the hill east of the Santa Rita basin. A small thickness of quartzite is said to cap the high mesa east of and overlooking Hanover Creek, and quartzite has been reported recently from the hills west of Hanover Creek and below the town of Hanover. These four occurrences of quartzite are considered by the writer as presumably parts of one formation, which is to be regarded as of later age than the quartzite exposed in and around the principal Santa Rita mines and in the Hanover mine. Whether or not this younger quartzite formation belongs at the horizon of the similar material which is found at Pinos Altos, Silver City, Bear Mountain, and Telegraph, and which in the Silver City section occurs between the Pennsylvanian and the Cretaceous, cannot be definitely stated, but such a position for it seems probable. This view is not in accord with those contained in private reports on the region made both before and after the present writer's visit to this district, and it must be admitted that the conclusions as to stratigraphic sequence here set forth are not regarded as thoroughly established. Further consideration will be given to this question on pages 309–311."

"Schist was found at only two places—the Santa Rita mine in the center of the Santa Rita camp and the Modoc tunnel, near the north

end of the Hanover district. The rock is very fine grained and either very dark brown or dark green, and where fresh shows the glistening surface of minute biotite flakes. Stringers and accretions of magnetite are common. At places in the Santa Rita mass are numberless tiny stringers of quartz. The microscope reveals the usual mosaic texture of the crystalline schists. Biotite is most abundant, followed by quartz and a feldspar that is not certainly determinable, but appears from its refractive index to be orthoclase. Magnetite, apatite, and zircon are present as accessories. Alteration produces serpentine abundantly, giving the rock a yellowish-green color, and as much of the rock exposed is somewhat altered it has received the local name 'greenstone.' The rock in the Santa Rita workings is similar to but a little coarser than that in the Modoc tunnel, and contains more magnetite. The supposition entertained at the time of its collection, that it might possibly be shale much metamorphosed by the near-by porphyry, was disposed of when microscopic study could be made. The rock is plainly the result of deep-seated regional metamorphism and is almost certainly pre-Cambrian. At both places the schist appears to occur as irregular bodies surrounded by the porphyry, as if torn from the parent mass and carried off in the porphyry melt. The mass in the Santa Rita mine is encountered on the 300-foot level and is at least several hundred feet in diameter. It is present under the quartzite found on the 200-foot level and is probably to be regarded as the Pre-Cambrian basement on which the sediments were deposited. The mass in the Modoc tunnel is more clearly a detached piece; so far as exposed it was surrounded by quartz monzonite porphyry and its relation to the limestone, which outcrops on the hill above, was not ascertained.

"Many of the facts regarding the structure and the attitude of the rocks have already been implied, and the question regarding sequence has been mentioned. The view that the quartzite found at the Santa Rita mines and at the Hanover mine lies below the limestones and is of Cambrian age is supported by the similarity of the rock to the known Cambrian quartzite west of Silver City and by the presence, probably immediately underlying it, of schist that must be regarded as pre-Cambrian. The conclusion that the limestone formerly overlay the ore-bearing rocks at Santa Rita had already been reached by S. F. Emmons. He says:[1] 'The ore is found in a white quartz porphyry,[2] which was evidently once covered by horizontally bedded limestones, that still lie round the rim of the shallow basin where it occurs.'

[1] Genesis of Ore Deposits, Special Vol. T. A. I. M. E., New York, 1902, pp. 449–450.

[2] The quartzite was apparently not separated from the altered porphyry that invades it promiscuously.

"Since 1905, when the region was visited a considerable amount of private geologic work has been done in the Santa Rita camp; the results of a part of these investigations have been published,[1] and recently the writer has been shown a private geologic report on the Santa Rita district made for the Santa Rita Mining Company in 1899. In both of these reports it is assumed that only one quartzite horizon is present in the region and that the quartzite in the heart of the Santa Rita camp is a down-faulted block. This view has been clearly presented in the older report, in which the opinion is expressed that the Carboniferous limestones underlie the whole Santa Rita property and that the quartzite lies above the limestones, separated from them by 150 to 280 feet of 'iron formation.' Concerning the relations of the limestone and quartzite in the heart of the Santa Rita camp the report says: 'The change from the . . . limestone country on the north and east to the more diversified geology of Santa Rita [quartzite, "iron formation," porphyries, and rhyolite] takes place abruptly along a ragged line. . . . Along this line in various places both the iron formation and the quartzites are brought into lateral juxtaposition with the limestones under such circumstances that their present relations can be explained only by supposing that the rocks south of this line have dropped, relatively to to main limestone block, to the extent of from 400 to 600 feet.' This reference to views not according with his own is made by the present writer because he feels that his own observations were not sufficiently detailed and extensive to establish his deductions conclusively, and it seems only fair to present all aspects of the question. The actual discovery and exact location of lines of faulting appear not to be mentioned in either of the private reports referred to, and, in both, the evidence of faulting seems to rest mainly on the assumption that the limestone is the lowest member of the column. Extending from the Kneeling Nun in a direction slightly west of north is a comparatively steep, serrated slope that forms the western boundary of the limestone mesa. This slope is to be regarded not as a fault scrap modified by erosion, but as the steep side of an anticlinal valley (Hanover Creek) formed by erosion of the elongated dome resulting from the intrusion of the quartz monzonite porphyry. The opposite or west wall of this valley is of gentler slope, but plainly exposes the same rocks forming the other limb of the anticline. This anticlinal structure is unmistakably evident through almost the entire length of the Hanover Valley. Santa Rita Creek has cut back into this steep east well and formed a depression or pass, through which leads the road to Georgetown. The limestone recedes up Santa Rita Valley, exposing quartzite (and porphyry), the boundary line of the limestone tending to conform with the

[1] Sully, John M., Report on the property of the Santa Rita Mining Company, Boston, 1909.

valley contours and the dip being away from the quartzite. It is evidently this situation that Emmons refers to when he says[1] that the limestones 'lie around the iron of the shallow basin.' This embayment in the limestone and the corresponding tongue of quartzite occupying the depression caused by Santa Rita Creek afford, perhaps, the best evidence in favor of the higher stratigraphic position of the limestone relative to the quartzite. The complicating feature of the 'iron formation' in the private report referred to is now, of course, explained as the zone of contact-metamorphosed limestone, a type of deposit whose nature ten years ago was seldom recognized and poorly understood.

"It seems probable, therefore, that the quartzite in the central part of the Santa Rita camp underlies the limestone. Nevertheless, the position in which it is found requires some explanation. If the quartzite is Cambrian, as seems probable, it lies of course at the base of the sedimentary series. But the full series is not present in the Santa Rita and Hanover districts, as is shown by sections at Georgetown, Lone Mountain and Silver City, nor is the quartzite present consistently between the limestone and the porphyry. The explanation of the presence of Cambrian and pre-Cambrian rocks in the Santa Rita camp and in the vicinity of the Hanover and Modoc mines in the Hanover district is believed to be that masses of these rocks have been torn off by the quartz monzonite porphyry magma and forced with it up through part of the overlying sediments to the abnormal stratigraphic position they now occupy. It may be that some of the lower limestones have likewise been brought up to a higher level and, being close to the magma, have been metamorphosed too much for determination. It may thus be that some of the shale exposed is from the underlying Devonian. If, therefore, as has been asserted by others, faults surround or bound this Cambrian quartzite mass, together with the pre-Cambrian schists and any older Paleozoic rocks that may have been forced up with it, the quartzite and adjacent rocks have probably been relatively raised rather than depressed along such faults."

The present writer is of the opinion that a much simpler explanation for the structure at Santa Rita is at hand.

To understand clearly the geology at Santa Rita and to appreciate readily the force of the relations there observed, it is necessary to have a clear conception of the geologic units which compose the larger area of which Santa Rita is but a small part. The simple but obscured relations within that basin will then become apparent.

[1] Emmons, S. F., *The Secondary Enrichment of Ore Deposits.* Special Vol. T. A. I. M. E., Genesis of Ore Deposits, p. 449.

Upon a basement of Pre-Cambrian granites (containing poorly defined inclusions of quartzite and schists), there has been deposited a series of sedimentary rocks comprising Upper Cambrian sandstones, Ordovician limestone, Silurian limestone, Devonian shale, Carboniferous limestone, Cretaceous quartzite, and Cretaceous shale with sandy layers. Upon this series of rocks, but following a prolonged period of erosion, Tertiary lavas have been poured out during successive eruptions between which, however, there accumulated considerable deposits of tuff and tuffaceous sands. Quaternary sedimentary deposits with interbedded basaltic flows have added their quota to this imposing succession.

Within this series two unconformities (there are more) are important. First that marked by the erosion interval preceding the deposition of basal Cretaceous quartzite and second, that marked by the erosion preceding the extravasation of the Tertiary lavas. Both of these unconformities are present at Santa Rita.

Intrusion, folding, and pronounced faulting have combined to disturb the original orderly sequence of this stratified series.

In addition to the late flows of lava already mentioned, a number of distinct periods of igneous intrusions have prevailed. First, the intrusion into (and perhaps extravasation upon) Cretaceous rocks of a complex of generally dark-colored porphyritic rocks of dioritic and andesitic facies associated with what appear to be volcanic breccias (and lavas) of a similar type; second, the intrusion of quartz diorite porphyry as laccoliths and stocks; third, the intrusion of holocrystalline masses of quartz-monzonitic, dioritic, and granitic rocks with associated porphyritic facies and accompanying dikes. These rocks cooled more slowly than their predecessors and solidified (at least the portions now exposed by erosion) before reaching the surface of the earth; fourth (and these followed the lavas already mentioned in the stratigraphic columns), the intrusion of stocklike masses comprising rhyolitic and latitic facies of fine-grained porphyries breaking through all the older rocks and through the lavas as well. Igneous activity was closed by the eruption of the late basaltic

lavas already mentioned in connection with the Quaternary gravels.

The earliest folding which has been recognized probably accompanied the intrusion of the holocrystalline dioritic and granodioritic masses. Such an assumption is based partly on the laccolithic nature of these intrusions and partly on physiographic evidence which need not be presented here. The earliest faulting that can be recognized followed the extravasation of the Tertiary andesitic and rhyolitic lavas, and its effect upon the configuration of the surface was far reaching. To it is due the monoclinal basin-range structure of several of the mountain masses of the area, and likewise the accumulation of deep and widespread deposits of Quaternary gravel. This faulting initiated perhaps in late Tertiary time has continued intermittently down to a very recent date.

This history of rather notable dynamic disturbance was accompanied by stages of important mineralization. But though it is not desirable to present at this time a classification of the several types of ore bodies which have resulted, a table is appended which epitomizes those geologic events which are important with respect to ore formation; and at the same time indicates the stage occupied by the deposits at Santa Rita.

THE STRUCTURAL AND GEOLOGIC RELATIONS AT SANTA RITA.

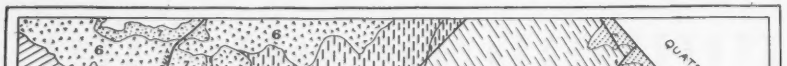
The geologic and structural relations at Santa Rita are more easily understood and more concisely correlated with the general geology of the region if an area of considerably wider extent than that of Santa Rita basin is described. Such an area is comprised in the geologic map shown in (Fig. 70).

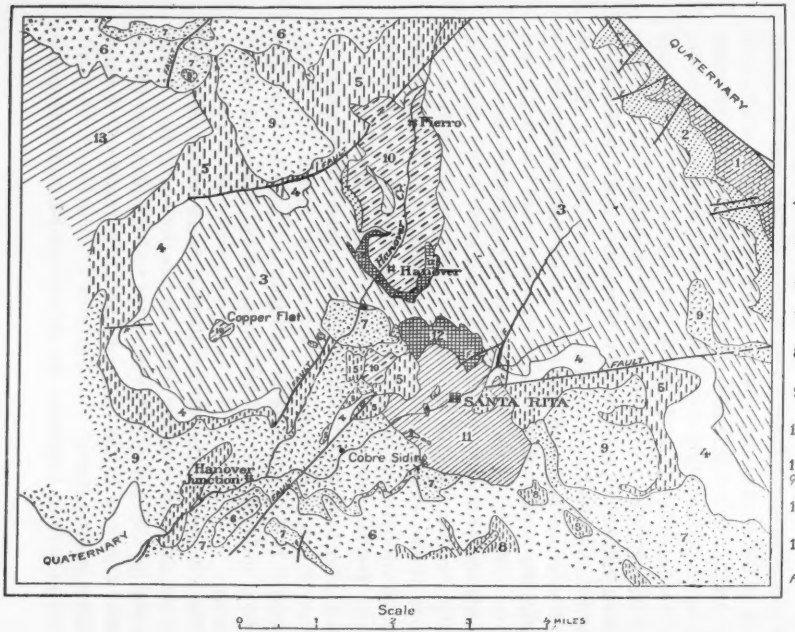
Two factors have contrived to obscure the geologic relations at Santa Rita. First, the intense metamorphism connected with the intrusion of quartz monzonite porphyry (granodiorite); and second, faulting. The first factor is peculiarly accentuated because of the lithologic similarity of the rocks which it effects.

Presented in the order of their occurrence the later geologic events recorded by surface relations to this area are:

TABLE SHOWING IN CHRONOLOGIC ORDER THE RELATION OF ORE FORMATION TO CERTAIN GEOLOGIC EVENTS.

	Geologic Events.	Type of Deposit.	Minerals.	Periods of Enrichment.	Character of Enrichment.
Partly pre-lava and post-lava.	Post-Cretaceous peneplanation combined with Recent erosion forming placers.	Placers near Pinos Altos.	Gold alloyed with silver.	Reconcentrated during Recent time.	Enriched placers.
			Sulphides of lead and silver.		
Post-lava	Post-lava faulting and subsequent mineralization of fault planes during intrusion of latitic porphyry stocks and dikes, with replacement of limestone.	Replacement of limestone by solutions at Chloride Flat, Georgetown, Lone Mountain, and Fleming Camp. Primary introduction of sulphides in faults. Veins at Hanover and Santa Rita. Quartz veins in Little and Big Burro Mountains.	Sulphides of iron and copper.	Enrichment during Quaternary and Recent time.	Native copper, oxides, carbonates, chlorides, and bromides with enrichment of gold-quartz veins by manganese-bearing solutions.
			Sulphides of lead, zinc, copper and iron with gold and silver with manganese-bearing minerals.		
			Cupriferous pyrite at Santa Rita and in Burro Mts.		
Post-Cretaceous and pre-lava	Fracturing and mineralization of granodiorite and monzonitic intrusives.	Primary mineralization at Santa Rita and in Burro Mountain and vein formation at Pinos Altos.	Sulphides of iron, copper, lead, zinc, with gold and silver at Pinos Altos.	Enrichment of upper portions of deposits, probably begun during Tertiary peneplanation and continued with interruptions up to present.	Native copper, oxides, carbonates, silicates. Enriched sulphides.
	Intrusion of a granodiorite or quartz monzonitic type.	Replacement of limestone near Hanover, Fierro, Copper Flat, and Santa Rita.	Magnetite, hematite, zinc sulphide. Copper and iron sulphide.		
	Intrusion of quartz diorite porphyry.		Sulphide of zinc, copper, lead and iron with associated gold and silver.		
	Intrusion of diorite and dioritic porphyry.	Replacement of limestone near Pinos Altos.			
Pre-Cambrian?	Small sulphide and galena veins.				





Legend

1 Silurian limestone
2 Devonian shale
3 Carboniferous limestone
4 Cretaceous quartzite
5 Cretaceous shale
6 Rhyolite lava
7 Tuff and sand
8 Andesitic and basaltic lava
9 Quartz diorite porphory
10 Grano-diorite (qtz Monzonite porphory)
11 Undifferentiated grano-diorite and quartz diorite porphury at Santa Rita
12 Metamorphosed limestone
13 Diorite-andesite-breccia complex
F Fault

FIG. 70. Geological map of the Santa Rita District, New Mexico.

1. The intrusion of quartz diorite porphyry laccoliths and stocks (see map, Fig. 70).

2. The later intrusion of quartz monzonite porphyry or granodiorite porphyry likewise taking a laccolithic form (the anticlinal structure in the Hanover-Ferro basin and the quaquaversal dips at Copper Flat suggest this relation). The central mass at Santa Rita is this type of porphyry though not separated on the map from the quartz diorite porphyry within the oxidized area, for reasons to be set forth below. These late granodiorite intrusions were accompanied by intense contact metamorphism, with all the usual results of such metamorphism where calcareous and argillaceous strata are involved. Of special structural interest in the present instance, however, is the metamorphism of the Cretaceous shale and sandy layers. These rocks have been altered to a resistant quartzite-like rock of generally light yellowish color intensely fractured and seamed with siliceous and limonitic veins. The metamorphism produced is probably as much the effect of later solutions following the intrusion of the porphyry as any immediate contact effect. Under the microscope the rock is seen to be made up of an even-grained aggregate of quartz and sericite specked with iron oxide. Epidote is fairly abundant. The present condition of the rock may be ascribed largely to that period of alteration which was accompanied by the primary introduction of pyrite. This rock breaks usually with a decidedly blocky fracture and may be distinguished from the porphyry which intrudes it by the lack of quartz phenocrysts which in the intrusive rock, even where most intensely altered, are always present. It may generally be distinguished from the basal Cretaceous quartzite by its fine-grain, yellow color and blocky cleavage.

The changes produced in the intrusive rocks of the region are also largely those resulting from solutions following very closely (probably) the cooling of the mass and taking advantage of numberless fractures in the rock produced by stresses whose cause remains undetermined.

As interpreted at present the older intrusive rock, the quartz

diorite porphyry, has been very severely metamorphosed by the after effects of the quartz monzonite porphyry intrusion. The prominent iron-stained hills which lie east, south, and west of the central core at Santa Rita are believed to be this altered quartz diorite porphyry or a quartzose phase of the same. Countless seams and cracks traverse this rock. Great quantities of secondary silica entered in numberless veinlets and the generally oxidized red appearance of the hills speaks of the original pyritization which took place. This rock is generally light in color, stained with iron oxide and intensely fractured and silicified. Quartz phenocrysts may usually be seen while the feldspars are changed to a dull white or dirty color. Under the microscope may be seen large resorbed phenocrysts of quartz, generally abundant, with completely sericitized and epidotized feldspars in a groundmass of quartz and sericitized feldspar. The ferromagnesian minerals have entirely disappeared. Not only are these rocks sericitized, but kaolinization is in places a very prominent alteration. Phenocrysts composed of nearly clear colorless kaolin may be seen under the microscope. With it very abundant secondary amorphous silica may be seen.

The quartz monzonite porphyry, the rock which by drilling has proved to be an important carrier of disseminated copper, is also much altered. The changes which have taken place in it are those which accompanied first the pyritization and later the oxidation of the rock. Abundant sericite has formed in the feldspars; biotite is chloritized, and kaolin is present. Sulphides are especially conspicuous. The rock is much seamed and fractured, but has not received the enormous accessions of secondary silica which seem to have made the surrounding hills of quartz diorite porphyry so resistant.

3. The alteration and mineralization which has just been described, affecting as it did the intruding as well as the intruded rocks, preceded Tertiary peneplanation. This fact is obvious when the position of the Tertiary lavas and tuffs (south of Santa Rita) are considered. These rocks rest upon an eroded surface. The intrusive rocks had already been stripped of their sedimen-

tary cover and been exposed to oxidizing conditions before this accumulation of lavas took place; meteoric waters had already initiated, and probably carried to a high degree, processes of secondary enrichment when the floods of lava suddenly and effectively brought such enrichment to a standstill.

4. Initiated by forces which have been active throughout the entire Rocky Mountain system there followed a period of severe faulting, the surface was broken into numerous fault blocks; porphyry intrusions accompanied the disturbance. A prolonged erosion interval stripped the lavas from the Santa Rita area. Two faults of this period are prominent in the vicinity of Santa Rita. One enters the district from the south, has a northeast southwest trend, a downthrow to the east, and passes a little west of Cobre Siding. The throw of this fault is elegantly expressed in the lavas southeast of Hanover Junction. The second fault enters Santa Rita from the east, has a nearly east and west trend, a downthrow to the south, and may be readily followed by the discordant structure produced between basal Cretaceous quartzite and Carboniferous limestone. The result of these two breaks is to make of Santa Rita a downthrown block and it is at once obvious that within the bounds of these two faults, the surface rocks are either Cretaceous shale (with interbedded sandstone lentils) or intrusive porphyries. Field observations bear out this interpretation. No rock was seen at the surface which could not be assigned either to a silicified phase of shale or sandstone lentil or to an altered phase of either granodiorite or quartz diorite porphyry.

We have in this basin therefore conditions peculiarly combined to create confusion if the two above described faults are not recognized. The silicified shale and sandstone closely resembles the basal Cretaceous quartzite found on the upthrow side of both faults and on the mountain top to the north, while the alteration of the intrusive rocks has made it impossible (without further detailed study) to delineate the boundary between granodiorite porphyry and quartz diorite porphyry within the silicified area. The writer holds the opinion provisionally (as stated above)

that this boundary is close to the base of the oxidized red hills east of the bed of Santa Rita Creek, the oxidized red hills being held to be in the main a greatly altered phase of the quartz diorite porphyry.

To epitomize the facts which it has been the purpose of this paper to present, it may be said that the area about Santa Rita is a downthrow fault block within which at the surface are exposed the highly silicified remnants of Cretaceous shales and sandstones intruded by at least two types of porphyry: first, quartz diorite porphyry, and second, quartz monzonite. A correlation of the silicified cretaceous shales with basal Cambrian quartzites is not borne out by the writer's observations. The quartz diorite porphyry is intensely altered and difficult to distinguish from the quartz monzonite porphyry.

The intrusion of the quartz monzonite porphyry was followed by fracturing and pyritization, not only of the intruding porphyry, but of the intruded shales and standstones and the quartz diorite porphyry as well. The first period of secondary enrichment began during a stage of pre-lava peneplanation but was interrupted by a covering of lava sheets. Faulting and the accelerated erosion initiated thereby again caused the porphyries to be exposed and processes of enrichment proceeded down to the present time. The faulting by bringing into juxtaposition metamorphosed shales (with sandy layers) and basal Cretaceous quartzites, contrived to conceal faults which otherwise might have been more readily recognized. The major portion of the ore body, as developed by drills at the time of the writer's visit, was disposed as a great ring surrounding a cove of quartz monzonite porphry. That the ore body may extend also into the fractured surrounding rocks is probable.

THE IRON ORE DEPOSITS OF THE CEBOLLA DISTRICT, GUNNISON COUNTY, COLORADO.[1]

JOSEPH T. SINGEWALD, JR.

The Cebolla district is located on the east side of Cebolla Creek, south of Powderhorn, in the southern part of Gunnison County. It lies about nine miles east of the Lake City branch of the Denver and Rio Grande Railroad, but is best reached by a stage line from Iola on the Denver and Rio Grande narrow gauge line which lies fifteen miles to the north.

The occurrence of titaniferous magnetite in this region has been known for some years, but no description of the deposit has ever been published.

J. K. Hallowell[2] visited the deposit in 1883, and said of it:

"The Cebolla iron deposit is a peculiar formation unto itself. I was asked regarding its geology; I had to weaken, I never saw anything like it, or read of anything similar. There is iron enough, over a mile square of it, apparently overlaid by trachyte at one time. The country rock is granite. The ore is heavy, black magnetite, of fair grade of iron, but carrying, as I was afterwards informed by one of the representatives of the Colorado Coal and Iron Company, too much titanium to be practically available in iron manufacture."

Regis Chauvenet[3] in a report on the Iron Resources of Gunnison County in 1887 makes the following mention of it:

"We come next to a region known as the 'Cebolla' district, situated near White Earth Creek (usually called Cebolla Creek), and at an average distance of about twenty-six miles from Gunnison City. This district lies very close to a proposed extension of the Denver and Rio Grande R. R. to Lake City, Hinsdale County.

"An immense ledge of titaniferous iron ore exists here, but little

[1] Published with the permission of the Director, U. S. Bureau of Mines.

[2] J. K. Hallowell, "Gunnison, Colorado's Bonanza County," *Colorado Museum of Applied Geology*, 1883, p. 106.

[3] Regis Chauvenet, "Iron Resources of Gunnison County." Annual Report of the State School of Mines of Colorado, 1887, page 18.

need be said of it. Samples taken from it vary greatly in their percentage of this objectionable material, the lowest I have ever analyzed yielding 9.38 per cent., and the highest 36 per cent. This last was rather to be classed as ilmenite than as iron ore. This deposit is enormous in extent, and is well worth exploitation with a view of ascertaining whether in parts, or at depth, it will not yield a product lower in titanium than any yet discovered. At present it must be condemned as unfit for smelting, at least by itself."

Two years later Chauvenet again refers to the deposit as follows:[1]

"Next, as a curiosity, not as a commercially valuable mine, I would name the Cebolla Creek titanium deposit. No one knows how the ore will hold out here, but as it can be developed in many places for some miles, it will last, in all likelihood, far longer than there is any use for it. It contains from 9 to 36 per cent. of titanic acid. We have all read in our text-books on chemistry, that titanium is a 'rare' metal. I do not think I risk much in saying that this is an inexhaustible stock of it."

In 1896, Authur Lakes[2] described deposits of non-titaniferous iron ore which occurs in the immediate vicinity of the titaniferous iron, but made only a brief reference to the latter. He examined the small opening close to the road, directly opposite the Cebolla Hot Springs, and described the ore as "gray massive iron" which is "mingled with streaks of brown mica and a green, somewhat asbestiferous-looking mineral, which may be hornblende or pyroxene."

Kemp[3] refers to the deposit and comments on the lack of information in regard to the ore or wall rock.

In the summer of 1905 or 1906, the district was visited by Van Hise and Leith[4] and is classed by them genetically with the Iron Springs District of Utah, that is, as a contact metamorphic deposit.

[1] Regis Chauvenet, "The Iron Resources of Colorado," *T. A. I. M. E.*, Vol. 18, 1890, p. 272.

[2] Arthur Lakes, "Iron and Manganese. The Great Cebolla River Deposits," *The Colliery Engineer and Metal Miner*, 1896, pp. 267–8.

[3] J. F. Kemp, "A Brief Review of the Titaniferous Magnetites," *School of Mines Quarterly*, 1899, p. 335.

[4] C. K. Leith and E. C. Harder, "The Iron Ores of the Iron Springs District, Southern Utah," Bulletin 338, U. S. G. S., 1908, pp. 92, 93.

The above information in regard to this district, though meager, is of such a character as to excite considerable interest from a scientific point of view. No titaniferous magnetites of contact metamorphic origin were known to me, and I remembered that Krusch cites the absence of titanium as one of the characteristics of these ores. In his "Untersuchung und Bewertung von Erzlagerstätten"[1] he says titanium is never present in these ores; and Beyschlag, Krusch, and Vogt[2] state that experience up to the present has been that these ores are characterized by an almost complete absence of titanic acid,—occasionally there is a trace present.

Here was apparently a highly titaniferous contact metamorphic magnetite deposit. It was with unusual interest, therefore, that I visited this district last summer in connection with a study of the titaniferous iron ores of the United States, which I am engaged in for the Bureau of Mines. As I was engaged solely in a study of the ores, I had opportunity only for a hasty geological reconnaissance. Consequently my observations were by no means complete; nevertheless, they were sufficiently so to make clear the essential features of this unusual ore deposit.

GENERAL GEOLOGY.

Fig. 71 is a geological sketch map of the district on a topographic base taken from the Uncompahgre Quadrangle.

The Cebolla district lies within a pre-Cambrian complex made up in this vicinity chiefly of granites and gneisses.

A little over a mile southeast of the Cebolla Hot Springs, a crystalline limestone is encountered along the road on the east side of the valley for a mile and a half, and has a maximum width of a little more than a mile. On the east side of the hill, just back of Powderhorn, similar limestone is again exposed.

Outcrops along the eastern edge of the valley, north of the limestone, are not so abundant on account of a heavier hill wash;

[1] P. Krusch, "Die Untersuchung und Bewertung von Erzlagerstätten," 1907, p. 179.

[2] Beyschlag, Krusch, Vogt, "Die Lagerstätten der nutzbaren Mineralien und Gesteine," Vol. I., 1909, p. 351.

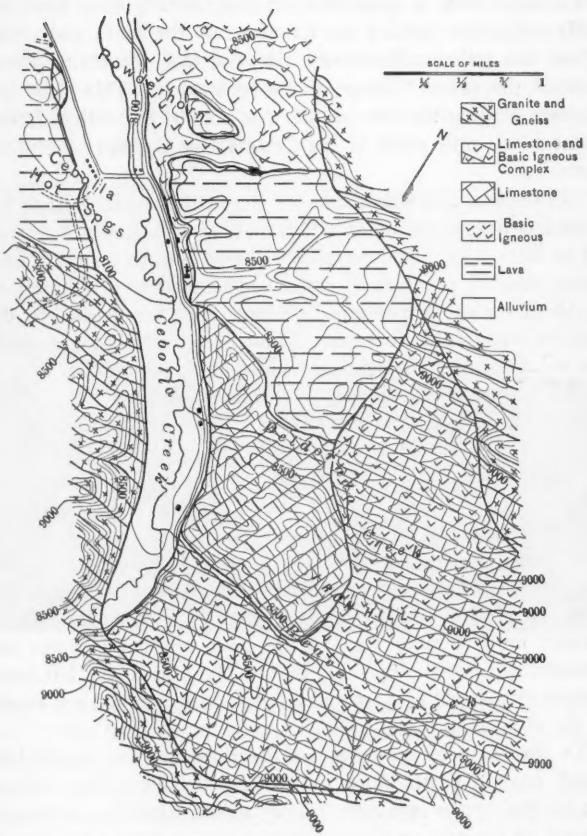


FIG. 71. Geologic Sketch Map of the Cebolla District.

but there are sufficient outcrops to show that the lower part of the hill slopes for some distance consists of a basic igneous rock. This basic rock is covered by a flow of rhyolitic lavas and tuffs which abut against the limestone on the south and extend about two miles to the north. Beyond this, the entire eastern side of the valley consists of the basic rock. This same lava appears capping the hills on the west side of the valley, from a point a half mile south of the Cebolla Hot Springs to Powderhorn.

On the east and south sides of the main limestone mass is a zone attaining a maximum width of over a mile, which consists of an intricately mixed complex of basic igneous material, limestone, and the products of contact metamorphism of limestone.

All of the above mentioned geologic units are marked by distinctive topographic features. These are clearly brought out by the accompanying geologic sketch map and photographs.

The limestone comprises two sharply defined hills, which project on all sides above the country immediately surrounding them. The larger of these is known as Iron Hill, and is shown in the photograph, Fig. 72, taken from the west side of the Cebolla valley. The southern end of the smaller hill shows in the left foreground of the picture. The lower country seen behind Iron Hill consists of the complex of igneous material and limestone, and is characterized by an irregular sort of topography. This extends part way up the slopes of the higher hill in the background until it gives way to the pre-Cambrian granites and gneisses which make up those hills. The hills in the left background are capped by a heavy flat-lying quartzite, and are known as the Huntsman Mesa.

To the north of the area just described are flat topped hills which have a gentle slope toward the Cebolla valley. These are formed by the lava flow. They abut against the gneiss and granite on the east, and are continued again on the west side of the Cebolla where the slope is away from the valley. Where erosion has cut deep enough, the basic igneous rock is exposed on the lower slopes of the lava capped hills. Fig. 73 shows the

hill directly east of the Cebolla Hot Springs. Several small prospect pits can be seen on its lower slope. The high hill in the background is the Huntsman Mesa, the valley in the foreground the Cebolla. North of these lava capped hills, the basic rock occupies the entire area between the Cebolla valley and the higher hills to the east, and the same irregular topography marks this area that is characteristic of the area underlain by the basic igneous and limestone complex.

FIG. 72. Iron Hill, Cebolla District.

The rocks of special interest in connection with the ore deposits are the basic igneous rocks, the limestone, and the lavas; and these will be discussed more fully below.

Another feature of interest in the district are the hot and mineral springs. The Cebolla Hot Springs are run into a pool, the water of which is at just about the highest temperature the body can endure. About two hundred yards from these is a soda spring. A quarter mile northwest of these springs is a large calcareous sinter cone, but the spring here is extinct. At

Powderhorn is a strong soda spring, the water from which tastes almost as strong as that from the famous soda springs at Manitou. Half way between this spring and the sinter cone mentioned above, alongside the road, is an iron spring.

FIG. 73. Titaniferous Magnetite Deposit capped by Lava Flow.

THE ORE DEPOSITS.

For convenience of discussion, the ore deposits may be divided into three groups: (1) Ores in the basic igneous rock, (2) ores in the basic igneous-limestone complex, (3) ores in the limestone.

1. *Ores in the Basic Igneous Rock.*

The basic igneous rock has undergone considerable differentiation, and shows rapid variation from place to place, especially in the ore bearing area. To the north of the ore bearing area, it consists of a dark greenish fine grained rock, in which locally considerable chalcopyrite is disseminated. The leaching of this

has given rise to green copper stain in crevices of the rock, and at one such point some prospecting has been done. Within the ore bearing area, the rock is somewhat coarser grained, and especially in association with the ores becomes very coarse grained. In general the coarse grained varieties are feldspar poor or free, though typical feldspar rich gabbro does occur. Most of these coarse varieties consist of coarsely crystalline aggregates of pyroxene, biotite, and ore in all possible ratios.

The richer ores consist of aggregates of titaniferous magnetite and bunches of dark brown mica which reach several centimeters in diameter. In such specimens, pyroxenes are not abundant. They grade over, however, into leaner ores in which the pyroxenes are more abundant, until a rock results which consists almost entirely of pyroxene. The ores are not entirely confined to these coarse rocks, but also occur as veinlets and stringers in the adjacent fine-grained rocks. These ores were prospected and worked to a slight extent about thirty years ago by a Mr. Crooks, of Lake City, who hauled some to the smelter located there at that time. Their titaniferous character was soon discovered and further shipments were refused by the smelter. The most extensive openings were made in a draw one mile northeast of the Hot Springs. Another opening, fifty feet long, was made just above the main road in the valley due east of the Hot Springs Besides these, numerous smaller openings have been made, especially in the area in which the basic igneous-limestone complex occurs. The ores throughout the area show the same features, both as to their mineralogical associations, and their geological occurrence. There is no evidence of the occurrence of any large ore bodies, but rather of a large number of very small ore segregations. No analyses of the ores were made, but the metallographic study of the ores which is in progress corroborates the high percentages of titanium given by Chauvenet. In almost all specimens examined, the ilmenite was far in excess of the magnetite. A detailed discussion of the manner of the intergrowth of the ilmenite and magnetite will be given in the report on the titaniferous ores of the United States now in course of preparation.

The composition of the ores, their mineralogical association, and their manner of occurrence establishes beyond doubt their genetic position. They are magmatic segregations of titaniferous magnetites in a basic igneous rock.

2. Ores in the Basic Igneous-Limestone Complex.

Petrographically this area affords a complete gradation from the basic igneous rock to a pure white coarsely granular marble. In some places the igneous rock has resorbed some of the limestone, so that calcite occurs in it as a primary constituent. At other places, limestone occurs in which large mica flakes are abundantly disseminated. Then again, typical products of contact metamorphism of limestone have been formed. The transitions are so rapid that one can pass from one extreme to the other within a few paces. The effect is that of a limestone mass which has been intricately intruded by the igneous. Sufficient time was not available to determine whether the intrusion took place in the form of a large number of distinct dikes, or in the form of irregular stocks. The complex is the least resistant of the rocks of the region, and hence has not afforded many pronounced outcrops.

The igneous rock is the same as that described in the preceding section, and associated with it are small ore segregations of the character described in that section.

The most interesting feature of this complex is the occurrence of small deposits of contact metamorphic ore. The product of contact metamorphism is usually a light green compact rock. In thin section, this rock is seen to be made up of calcite, augite, garnet, and less abundantly, of zoisite and vesuvianite. The relative abundance of these minerals varies greatly in different specimens. There frequently occurs, as phenocrysts as much as five centimeters long, a dark augite with purplish tinge. Less abundant than this light green dense rock is a somewhat coarser dark rock which contains a larger percentage of yellow to brown garnets and deeper-colored augite. Within the contact metamorphic rock are numerous pockets and nests of magnetite. These

pockets of ore, though small, contain very little gangue. They are usually separated from the surrounding light green rock by a narrow zone of the darker coarse-grained mixture of garnet and augite. A study of polished sections of this ore showed that it consists of both ilmenite and magnetite; and, though apparently not as abundant in amount as in the magmatic segregations, the ilmenite forms a considerable part of the ore. From a scientific standpoint, this is the most important and striking feature of the district—the occurrence of highly titaniferous iron ore of contact metamorphic origin.

3. *Ores in the Limestone.*

The limestone in the district, wherever exposed, has been more or less replaced by iron. On Iron Hill, the ore is principally siderite and limonite. In the small hill to the north, the resulting product is chiefly a yellow ferruginous jasper and highly siliceous limonite. Silicification is far less prominent on Iron Hill. At some places the siderite has changed to hematite, though the structure and cleavage of the siderite is still retained. In the ravine on the west slope of Iron Hill, is a series of exposures in which there are frequent gradations of limestone to siderite, and disseminated throughout this are small crystals of magnetite and martite, from one to three millimeters in diameter. Farther up this same ravine a very high grade ore occurs. This consists of large crystals of specular hematite and magnetite in a matrix of siderite, the siderite forming but little more than fifty per cent. of the whole. Tests of this magnetite and hematite gave titanium reactions. The siderite showed no titanium.

Dozens of prospect pits have been put in on the two hills, and these, together with many natural outcrops due to the rugged topography of the hills, afford abundant exposures of the ore. The property is at present owned by Mr. Robert Lewis, of Gunnison, by whose father the claims were patented. It is this ore that is described by Arthur Lakes in the reference given above. Lakes lays considerable stress on the occurrence of manganese ore. The greater part of the ore body, however, is free of man-

ganese; and certainly it does not contain sufficient manganese to be used in the manufacture of spiegel as he suggests. The following average analysis of the ores obtained from Mr. Lewis is cited by Lakes:

AVERAGE ANALYSIS OF ORE IN LIMESTONE.

	Per Cent.		Per Cent.
Silica	3.15	Iron peroxide	69.04
Alumina	1.61	Sulphur	trace
Lime	8.60	Titanic acid	trace
Mn. oxide	1.60	Metallic iron	54.91
Iron protoxide	8.46	Phosphorus	1.53

Iron Hill includes an area of one square mile, and has a maximum altitude above the Cebolla of one thousand feet. The smaller hill has an area of more than a quarter square mile, and an altitude of six hundred feet. The tonnage of these two hills to the level of the Cebolla is more than one billion. If the above composition of the ores were an average of the whole, this would be an extremely important ore deposit. There are, however, considerable portions too lean to work, so that the actual tonnage of workable ore falls far below the figures just given; and it is in all probability so involved with the unworkable material as to make the whole deposit unworkable, at least until there is a far greater demand for iron ore in that part of the country than at present is the case.

Lakes gives a very ingenious explanation of the origin of this ore, but one which will hardly find many adherents. He says:

"The ores are not the product of fire heat; they are not nor ever were in a molten condition like lava. They are the products of water and that in a heated state, in other words, hot mineral springs, not unlike, perhaps, those still represented in miniature at the Cebolla resort, which are daily depositing both iron and manganese and calcspar, the same components as these great hills.

"Though not the direct result of igneous eruption, the hills may have an indirect relation to such eruptive agencies. We have observed the prevalence of eruptive rhyolite (a lava closely allied to trachyte) in flows and dykes adjacent to the iron and manganese hills terminating at those hills.

"Hot spring or solfataric or geyser actions, together with a great

variety of hot or cold mineral springs, are the natural and common accompaniments of the dying efforts of volcanic activity. . . .

". . . One of the principal effects of hot water and steam emanating from these hot springs is the decomposition and leaching out of soluble minerals and metals contained in the enclosing rocks from great depths even to near the surface. On reaching the surface the waters, laden with the solutions which they have acquired in their upward course, deposit or precipitate it in solid oxidized form around their orifice. . . .

"What, then, these comparatively little hot springs are doing daily on a small scale where igneous activity has long ceased or become dormant, that, we conceive on a vast scale and for a long period of time was carried on in the area where the iron, manganese and calcspar mountains now stand, when igneous forces were more energetic or had but a short time to become latent."

In other words, Lakes considers it a gigantic hot spring deposit. There is no reason for ascribing any such unusual origin to a deposit of this type. It is manifestly a replacement of an original limestone mass, relicta of which are still preserved. Insofar as he points to hot waters and an igneous source for them, he is doubtless correct. The query then comes were the mineralizing solutions derived from the basic igneous rock or from the acidic magma of the lava flows. The presence of a trace of titanium in the hematite and magnetite replacement on Iron Hill would point to solutions emanating from the basic rock. In that case, this portion of the limestone mass lay without the influence of direct contact metamorphism; and it was replaced by hydrothermal solutions given off by the basic magma. The one serious objection to this is the great amount of silicification that has taken place, and the fact that silicification has been most pronounced where the deposit lies nearest to the lava flow. This would indicate that the silica at least was derived from the acidic magma. On the other hand, consideration must be taken of the fact that the basic magma has shown itself to be highly iron-bearing by the formation of magmatic segregations and contact metamorphic deposits of iron ore. It is only natural therefore to look to it as the source of the iron-bearing solutions. It seems not improbable that the iron-bearing solutions came from the basic magma; and that silicification took place at a subsequent period,

immediately after the extrusion of the lavas. To finally answer this question a more detailed study of the occurrence is necessary.

TIME OF MINERALIZATION.

The fixing of the period of mineralization is impossible with the information at hand. One of the first problems that must be solved is the meaning of the presence of the limestone. Its occurrence in this pre-Cambrian area must be explained. Is it of pre-Cambrian age, or is it a younger limestone that has come into its present position through tectonic disturbances? Younger than it is the basic igneous rock. Representing the Tertiary period of igneous activity in the San Juan country are the rhyolitic lavas and tuffs. These are the youngest rocks of the series. The magmatic segregations and the contact metamorphic ores are certainly older than these; the replacement ores are probably older; and the silicification may be directly due to these rocks.

RÉSUMÉ.

The Cebolla district lies within an area of pre-Cambrian rock consisting of granites and gneisses. The rocks immediately connected with the ores are basic igneous rocks, limestone and rhyolitic lavas. The basic rocks contain numerous small magmatic segregations of highly titaniferous magnetite. The limestone has been in part intruded in a most intricate manner by the basic rock; and has been contact metamorphosed by it, giving rise to small deposits of magnetite which are remarkable on account of their highly titaniferous character. The remainder of the limestone has been for the most part replaced by ferruginous hydrothermal solutions. Whether this is the result of solutions derived from the basic magma or from the acidic magma cannot be stated with certainty. The presence of titanium in the magnetite and specular hematite in this ore makes the former the more probable. The areal distribution of the silicified portions of the limestone and the lavas would point to the acidic magma as the source of the siliceous solutions. On account of the lack

of knowledge as to the age of the limestone, no definite limit can be set to the period of mineralization. The magmatic segregations and the contact metamorphic ores are of no economic importance; the limestone replacement deposits are of doubtful economic value at the present time, but may form important sources of ore at some future time when there is greater demand for iron ore in that section.

THE STRUCTURAL RELATIONS OF THE OIL FIELDS OF CRAWFORD AND LAWRENCE COUNTIES, ILLINOIS.[1]

RAYMOND S. BLATCHLEY.[2]

The Geological Survey of Illinois began a detailed investigation of the geological conditions in the southern half of the eastern Illinois oil fields in 1908. The work was carried on intermittently and was finally completed January 1, 1912. The specific area of investigation lies in the southern half of Crawford and the central portion of Lawrence counties. The primary object of the work was to determine the cause of the accumulation of oil and gas and to secure facts which would have a bearing on the theory of their origin and also, to determine, if possible, the relation of the quantities of oil, gas, salt water, porosity of the sand, etc., to the structural features of the sand.

The work is based upon the elevations and records of 5,200 wells. The method of study is to map by means of contour lines the geologic structure of the producing sands. The contours are made upon the positive altitudes of the sands above a datum plane 1,500 feet below mean sea level. Several of these maps show the oil sands as if everything above them had been removed. From the undulations on the surface of the sands and from the initial productions of the wells, the oil, gas, and water relations to the structure are observed. In addition to the contour maps cross-sections are made along chosen lines on the crest of the anticline and crosswise to it. These graphic sections make clearer the contour maps and reveal the vertical amplitude of the arches. From all the data obtained it is clear that the La Salle anticline is the controlling feature of the field.

[1] Read before the Illinois State Academy of Science, February 23, 1912, Bloomington, Illinois. Printed with permission of the Director of the Geological Survey.

[2] Geologist in charge of oil studies, Illinois State Geological Survey.

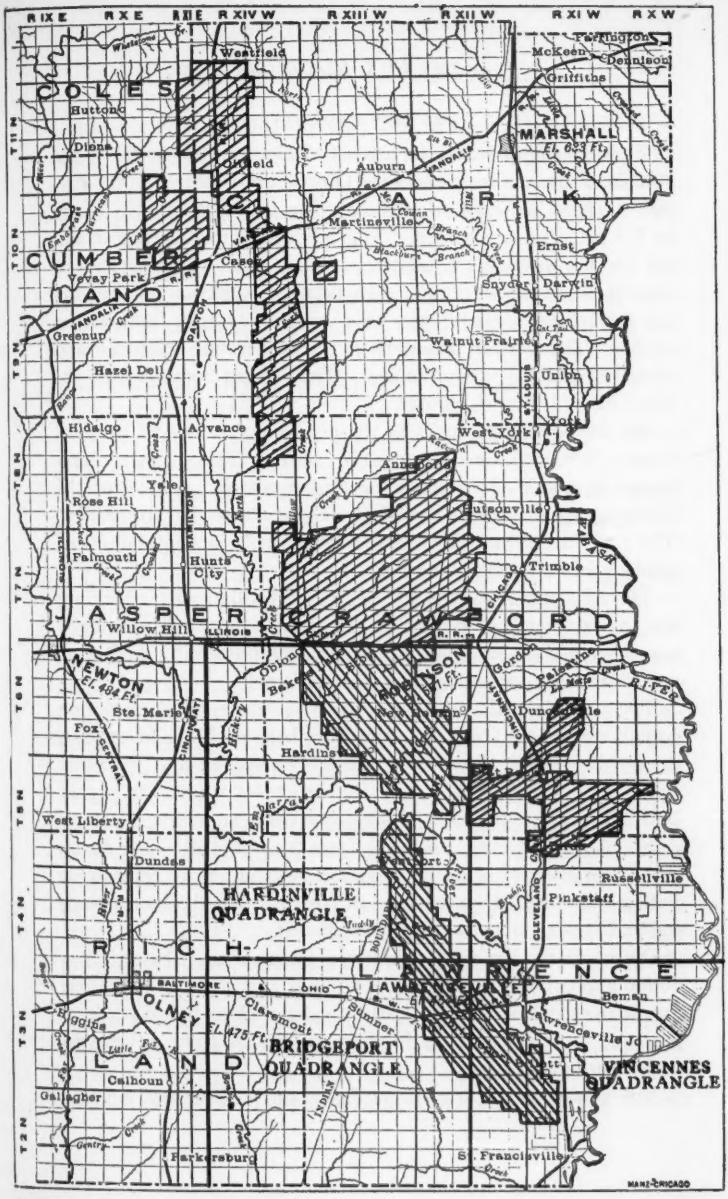


FIG. 74. General map of the main oil fields of Illinois.

CRAWFORD COUNTY.

The investigated area in Crawford County lies south of the Illinois Central railroad, between Oblong and Robinson (see Fig. 74). There are 2,970 wells mapped in this area, of which 206 or 8.7 per cent. are barren. The productive wells range in initial yield from 1 to 1,600 barrels. The Robinson or Crawford County pool is about 7 miles wide between Robinson and Oblong but it narrows to about 3½ miles at the southern limit of the county. The western boundary of the field trends northwest and southeast and is sharply defined. The eastern boundary, on the other hand, is very irregular.

All the penetrated rocks in the producing areas of Crawford County belong to the Pennsylvanian series. This series is represented by about 480 feet of the McLeansboro, 300 feet of the Carbondale, and about 100 feet of the Pottsville formations. The rocks are principally shales with variable intergradations of sandstones, limestones, and coal.

The oil sands lie at the top of the Pottsville rocks, which are the lowest members of the Pennsylvanian and are essentially coarse sandstones merging into sandy shales at the top and often split with lenses of shale and pockets of coal.

The Crawford County pools have one general oil producing zone known as the Robinson sand lying between 800 and 975 feet deep. This sand however is usually so broken and lenticular that it offers little opportunity for structural study. It is split into two or three persistent lenses that show an average interval of about 50 feet and a thickness from 2 to 50 feet. The lenses often merge into each other and are even united in some wells with a maximum thickness of 122 feet. Again the lenses pinch out and in several wells are entirely absent.

Owing to the irregular deposition of sands and shales it was found impossible to correlate and contour any sand beds definitely except the top lens of the Robinson sand. Even this work loses much of its scientific value in places where the sand wedges out or is overlapped.

The general structure of the Robinson pool reveals a broad

and gentle arch which is divided into two parts by a transverse basin. The north part of the arch is 6 miles wide, with its crest 95 feet above the lowest explored portions of the limbs. The south part of the arch is about 4 miles wide and 110 feet high.

In studying the distribution of oil over Crawford County the lower lenses are found slightly more productive than the top lens. There is considerable unevenness of distribution due to the following factors:

1. The sands vary in porosity and in many places are practically impervious to oil.

2. The sands thin and thicken rapidly and in some localities pinch out altogether.

3. The sands are so closely interbedded with the shales along the productive zone in some areas as to prohibit extensive collection of oil, gas, and water.

4. The best productive areas have 20 to 40 feet of sand and are usually free from large amounts of salt water.

5. Local dry spots in the midst of very productive territory cannot be attributed to small depressions or knolls in the sand bodies but rather to the non-porosity of the beds.

Salt water does not uniformly fill the rocks of the region, although there are many dry strata which are porous. Great quantities of salt water occur upon the limbs of the anticline beyond the productive area and in the Illinois basin to the west. All the lenses of the Robinson sand are well saturated along the definite boundary line on the western side of the pool. The upper lenses are generally barren of water within the pool while the lower lenses reveal water across the fold and, in some localities, under the oil. Since the oil lies near the top of the lower sand lens but few wells pass through the oil stratum into the water for fear of drowning out the oil.

It is obvious from the position of the water and oil along the LaSalle anticline that the water has controlled the accumulation of oil in the arch. The water probably has originally permitted the oil to migrate long distances up the slope of the Illinois

basin into the arch. This was effective for all lenses of the Robinson sand, although the degree of saturation is variable over the crest of the arch.

LAWRENCE COUNTY.

The oil field of Lawrence county offered the best opportunity for geological study because of the depth and number of oil horizons and the abundance of records. The field is 17 miles long and three miles wide. There were 2,180 wells mapped, of which 156 or 5½ per cent. were dry. The range of initial production lies between 1 and 2,400 barrels. The field trends northwest and southeast with the northern limit on the Crawford-Lawrence county line. The field changes its course about 20° near Bridgeport. The western edge of the field is well defined like that of Crawford county and, similarly, the eastern edge is irregular. The Lawrence County field is the richest in Illinois and has produced more large wells with steadier yield than the rest of the fields combined.

The explored rocks of Lawrence county lie in the Pennsylvanian and Mississippian series. The former are from 800 to 1,300 feet thick; the latter are, as a rule, penetrated only to a depth of about 475 feet. The columnar section presented (Plate IV) is made up of logs from all sections of Lawrence county These are arranged in order from south to north with correlation lines showing the stratigraphic relations.

The Pennsylvanian rocks of Lawrence county include a shallow producing sand at the south end of the field, probably in the McLeansboro formations; the Bridgeport sand of three lenses, in the upper part of the Pottsville formations and corresponding to the Robinson sand of Crawford county; and the Buchanan sand in the basal portion of the Pottsville rocks.

The Mississippian rocks underlie the Pennsylvanian and contain the most important oil sands. The upper part is known as the Birdsville and Tribune (Chester), followed by the Ste. Genevieve and the St. Louis limestones. The Chester beds include the so-called "Gas," Kirkwood, and Tracey sands, while the

Ste. Genevieve contains the rich McClosky sand. The sand names are those of landowners upon whose farms the sands were first tapped. The Chester rocks average 365 feet in thickness in comparison with 700 feet in southwestern Illinois.

The "Gas" sand or first sand in the Chester, produces gas locally over Petty Township of Lawrence County. It is 125 feet beneath the top limestone of the Chester and 198 feet lower than the Buchanan sand of the overlying Pottsville.

The Kirkwood sand is the most widespread producing horizon in Illinois, as well as in Lawrence county. It is correlated with the Sparta sand of Randolph county, the Carlyle sand of Clinton county, the Lindley sand of Bond county, the Benoist sand of Sandoval in Marion county, all of Illinois, and the Oakland City sand of Pike county, Indiana. The Kirkwood sand shows excellent initial production and long continued yield. It is the most reliable of all the sands. The oil is "sweet" or with small percentage of sulphur. The top of the Kirkwood sand is 192 feet beneath the top of the Chester, 67 feet below the top of the "Gas" sand and usually lies about in the middle of the Chester rocks.

The Tracey sand is stratigraphically equivalent to the Cypress sandstone and is usually about 317 feet lower than the top of the Chester and 114 feet beneath the Kirkwood sand. This sand yields gas under high pressures and some oil. The gas has a rank odor and the oil from this sand is "sour," both due to the large sulphur content. The Tracey sand is so closely associated with the underlying limestones that its oil and gas probably had its origin from the included marine animal life of the limestones.

The Ste. Genevieve limestone has a total thickness of 85 feet and contains the McClosky sand, which has proven the most prolific oil horizon in Illinois, because of exceptional initial flow and steady yield. This pool has been instrumental in upholding the Illinois production when other sections were declining. The range of depth for the sand is 1,550 to 1,850 feet or about 446 feet lower than the top of the Chester and 104 feet beneath the top of the Tracey sand. The oil is found 20 to 50 feet in the limestone.

The detailed structure of the Lawrence county oil field is shown in the detail report in this region by five contour maps of oil sands and by four cross-sections of the field. The structure map of the top of the Kirkwood sand is the most representative. The altitudes of this sand were assembled and contoured with 20-foot interval. The most conspicuous feature revealed is a double plunging anticline or elongated dome with its crest lying in section 30, Petty township, T. 4 N., R. 12 W. The crest of this dome lies within the 680-foot contour above an assumed datum plane, 1,500 feet below sea level. The sand dips from the crest of the dome northward at the rate of 41 feet per mile; southward, 63 feet per mile; eastward, 194 feet per mile; and westward, 228 feet per mile. The sand dips southward from the dome into a small syncline in the southwest corner of Lawrence township and then spreads fan-like in its structure to the southeast through Lawrence and Dennison townships on to a broad plateau-like crest of the major fold. In this locality the sand lies at the 400-foot contour level. The southern limits of the field seem to gradually dip lower than the producing zone of the sand. Whether the major fold continues to dip and merge into the southeastern side of the Eastern Interior coal basin or the dip is local as seems to be the case between Crawford and Lawerence counties, is not known.

The other structure maps of the Buchanan, "Gas," Tracey, and McClosky sands corroborate and conform to the structure of the Kirkwood sand with the exception of very minor irregularities. In addition to these maps four cross-sections were made to show the nature of the crest of the LaSalle anticline, as well as its flanks. The sections are chosen along lines that pass through or near a large number of wells. The cross-sections were constructed by plotting records with uniform symbols and scale. The records are located with respect to section and township and to their position above sea level. Wherever the cross-section line crosses a contour on the structure maps the altitude of the contour is marked with a cross and set in its proper position. Correlation lines drawn between crosses represent the actual lie of the

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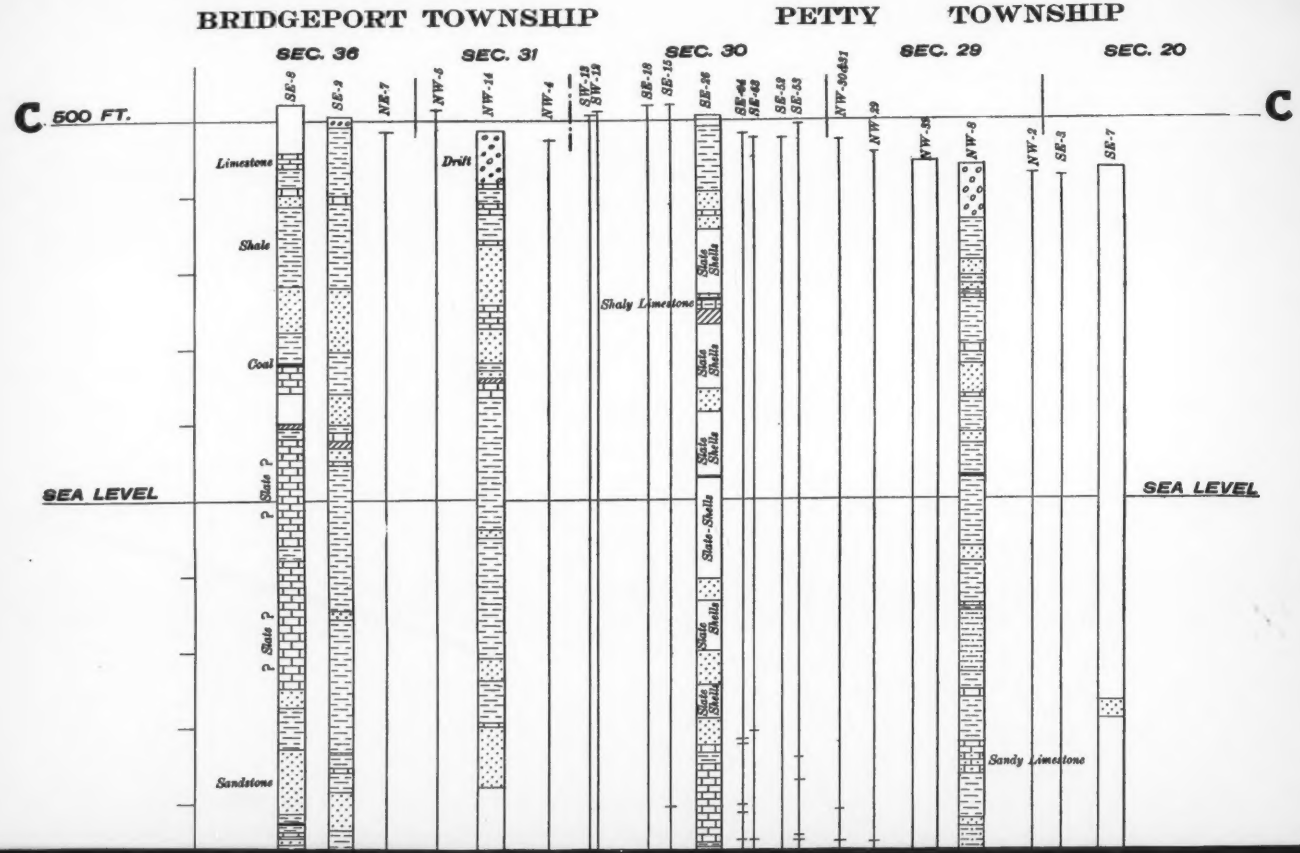
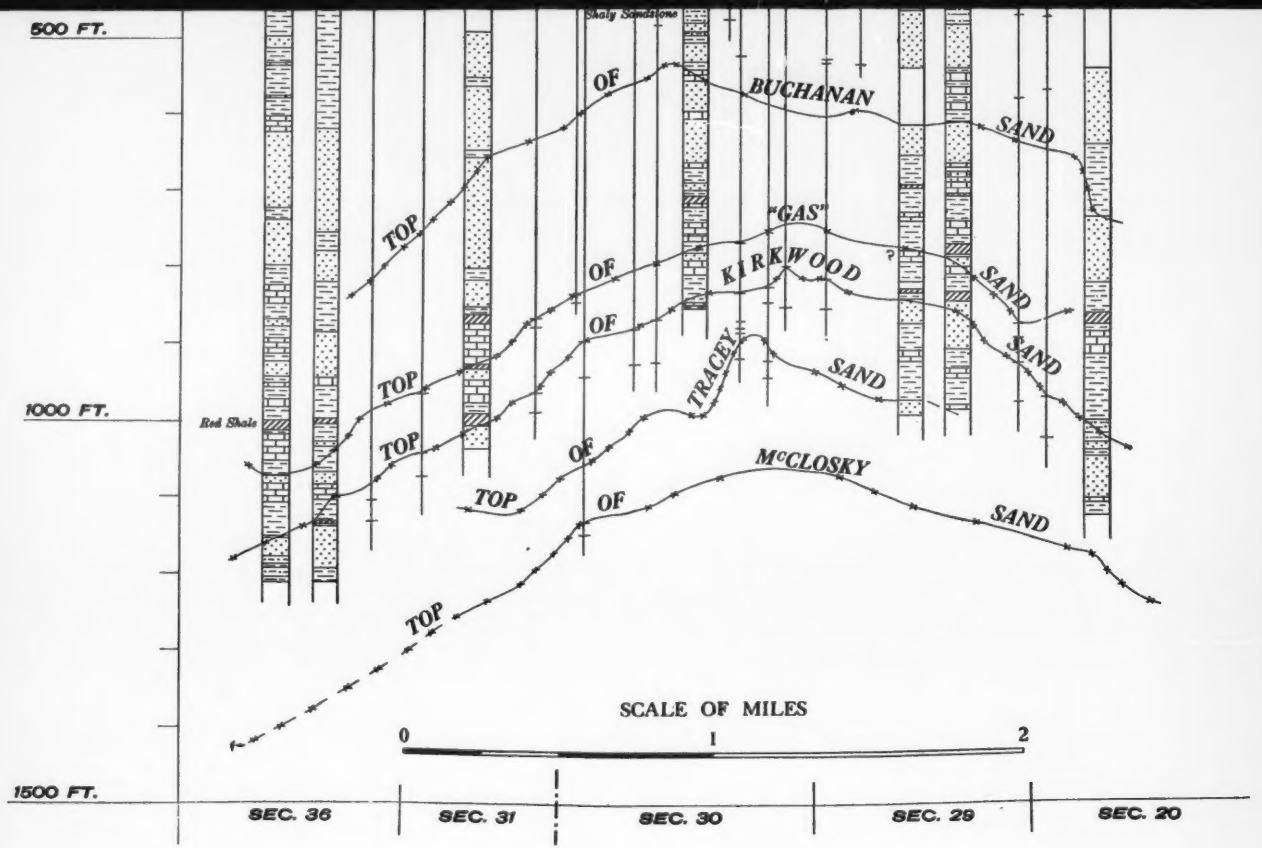
PLATE III.

BRIDGEPORT TOWNSHIP PETTY TOWNSHIP

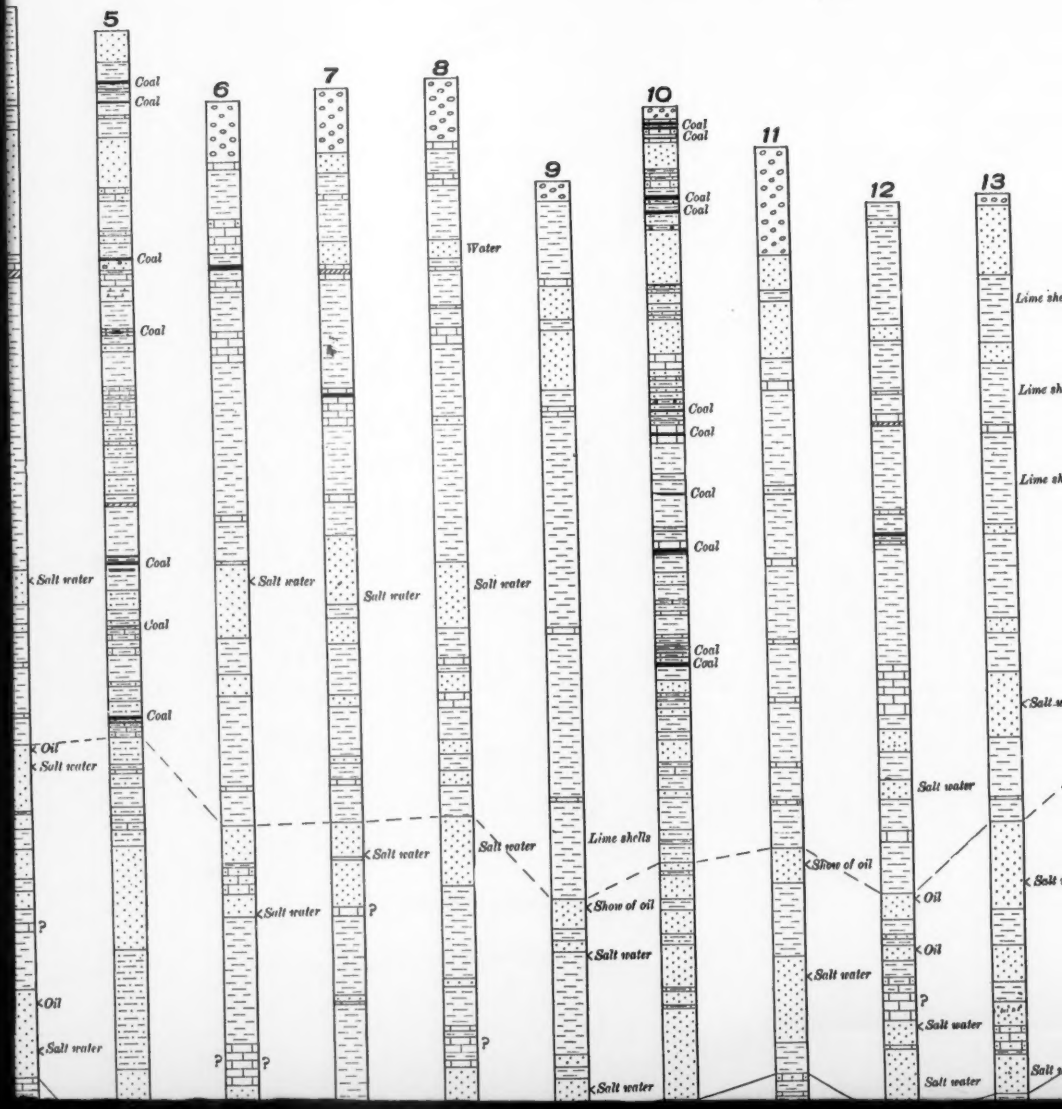

BRIDGEPORT TOWNSHIP
PETTY TOWNSHIP
SEC. 36
SEC. 31
SEC. 30
SEC. 29
SEC. 20
C
500 FT.
C
SE-9
SE-3
NE-7
NW-5
NW-14
NW-4
SW-13
SW-12
SE-18
SE-15
SE-36
SE-44
SE-43
SE-53
SE-53
NW-30431
NW-29
NW-35
NW-8
NW-2
SE-8
SE-7
Limestone
Shale
Coal
Shale ?
Shale ?
Shale ?
Sandstone
Drift
Shaly Limestone
State Shells
State Shells
State Shells
State-Shells
State Shells
State Shells
Sandy Limestone
SEA LEVEL
SEA LEVEL

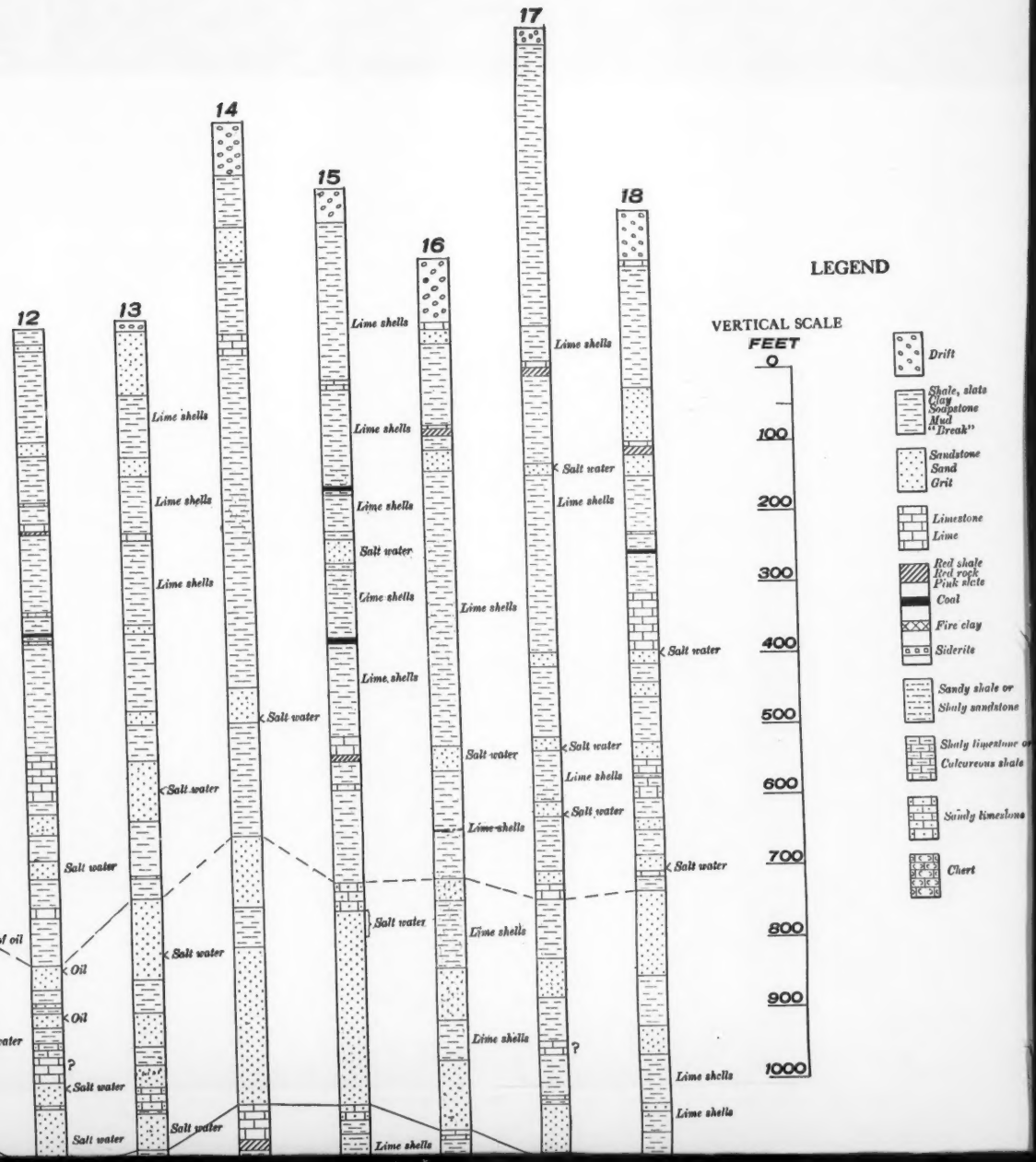


CROSS-SECTION OF THE LA SALLE ANTICLINE.

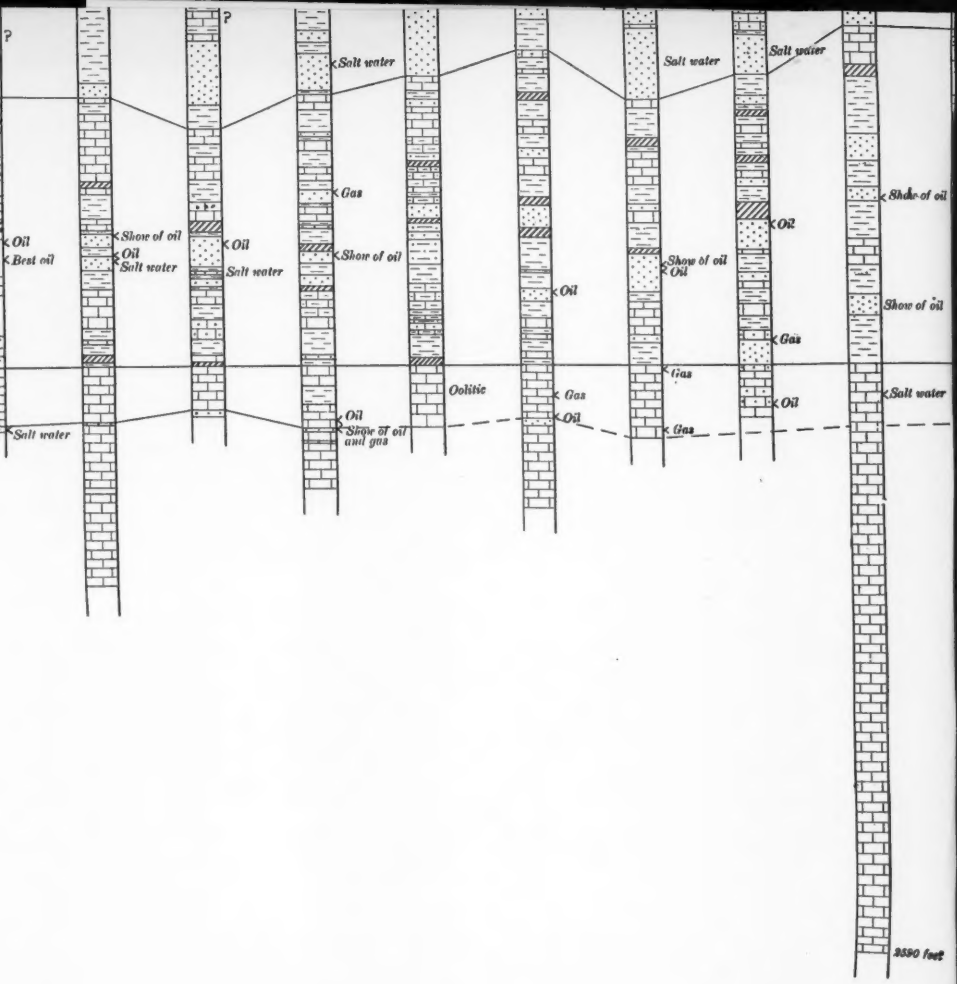
PLATE IV.

CROSS-SECTION OF THE LA SALLE ANTICLINE.

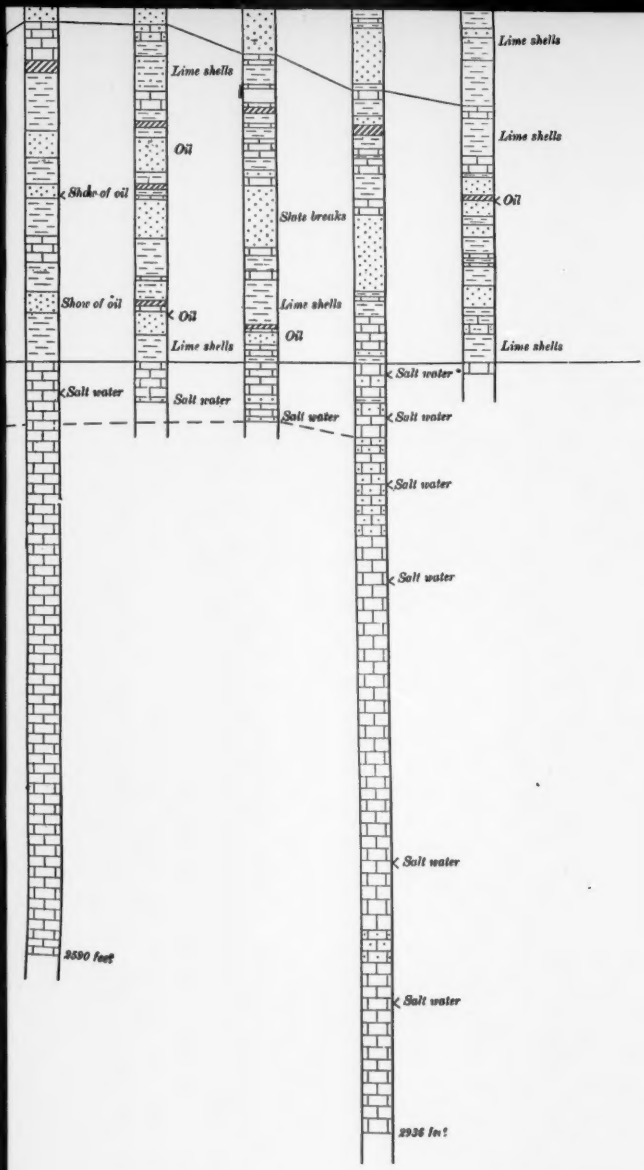

5
Coal
Coal
Coal
Coal
Coal
Coal
Coal
Salt water
Oil
Salt water
?
Oil
Salt water
6
Salt water
Salt water
?
?
7
Salt water
Salt water
Salt water
?
8
Water
Salt water
Salt water
?
9
Lime shells
Show of oil
Salt water
Salt water
10
Coal
Coal
Coal
Coal
Coal
Coal
Coal
Coal
Coal
Coal
11
Show of oil
Salt water
12
Salt water
Oil
Oil
?
Salt water
Salt water
13
Lime sh
Lime sh
Lime sh
Salt w
Salt
Salt


12
13
14
15
16
17
18
Lime shells
Salt water
Oil
?
LEGEND
VERTICAL SCALE
FEET
0
100
200
300
400
500
600
700
800
900
1000
Drift
Shale, slate
Clay
Soapstone
Mud
"Break"
Sandstone
Sand
Grit
Limestone
Lime
Red shale
Red rock
Pink slate
Coal
Fire clay
Siderite
Sandy shale or
Shaly sandstone
Shaly limestone or
Calcareous shale
Sandy limestone
Chert

MISSISSIPPIAN
CHESTER
ST. GEN-EVIEVE
ST. LOUIS
Salt water
Show of oil
Salt water
Oil
Oil
Oil
Oil
Oolitic
Oolitic
Oolitic
Oil
?
Salt water
Salt water
Salt water
Salt water
Salt water
Oil
Oil
Oil
Place of
?
Salt water
Show of oil
Hard
Oil
Soft
Hard
Oolitic
Oolitic
Oolitic
Oolitic
? ?
Oil
Best oil
Salt water
Show of oil
Oil
Salt water



DEEP WELL SECTIONS OF LAWRENCE COUNTY, ILLINOIS.


Lime shells
Lime shells
Oil
Show of oil
Slate breaks
Show of oil
Oil
Lime shells
Lime shells
Oil
Lime shells
Salt water
Salt water
Salt water
Salt water
Salt water
Salt water
Salt water
Salt water
Salt water
2590 feet
2936 feet

sand and picture any rise or fall. One section, known as the A-A, Plate III., presents the structure of the sands along the crest of the anticline and lengthwise through the oil field. The section is valuable for its picture of the double plunging anticline, the convergence of the sands at the northern end and the mergence of the dome into the flat at the southern end of the field. The sands are generally parallel with local irregularities that seem due in most cases to the thinning and thickening of the sand.

The C-C section (Plate III.) is chosen along a line crossing the crest of the conspicuous elongated dome. This shows the extreme relief in structure of the Lawrence county field. The dome is about 400 feet high and 3 miles wide.

The largest amounts of oil in the Lawrence County field are in the extensive flat area in the southern half of the field and at a level of about 60 feet below the crest of the dome in the northern division.

The sands of Lawrence county show abundant water along the lower flanks of the anticline and but little through the center of the field except in the lower Bridgeport and Buchanan sands. These Pottsville rocks appear well saturated with water over the entire field and into the limbs of the LaSalle fold. The underlying Chester sands are not uniformly saturated with water but seem to have lines of saturation along the limbs of the fold,—more particularly along the western side.

SUMMARY.

The features of the structure maps and their individual oil, gas, and salt water relations, just described, are sufficiently similar to permit general conclusions regarding the accumulations of oil and gas in Crawford and Lawrence counties. These conclusions add to the general fund of evidence relating to the accumulation of oil and gas in raised rocks.

The greater part of Illinois lies within the Eastern Interior coal basin, which is, broadly speaking, an extensive spoon-shaped basin, with its axis extending along a line, through Cerro Gordo, Lovington, and Olney and into its deepest part in Wayne, Hamil-

ton, and Edwards counties. The east side of the basin rises into a strong longitudinal fold known as the LaSalle anticline. The ascent is at the average rate of about 50 feet per mile but it is more rapid in Lawrence county as shown by contours of the very sharp apex of the anticlinal dome. The basin and lower flanks of the fold are known to yield abundant water in all the sands which are productive in the main fields. The uppermost part of the flanks of the major fold contain abundant oil. The western limits of the fields are abrupt and beyond this line the sands are wholly water-bearing. Enough data are at hand to conclude that this is a line of water saturation and that above this line and over the fold most of the sands are oil bearing.

The accumulation of oil and gas in their present position may be looked upon as ideal and is presumably due to the following factors:

1. There is an extensive anticline with a marked basin on at least one side.

2. The depressions on both sides of the fold, showing abundant water, comprise extensive "feeding" areas for the arch.

3. The sands are commonly porous and hence form suitable reservoirs.

4. There are abundant shales and some limestones overlying the sandstones, which probably serve as impervious covers to the reservoirs.

5. The sands in both limbs of the anticline are abundantly saturated with salt water, which is probably instrumental in holding the oil and gas captive in its present position.

6. Although the general structure of the oil fields is dominated by a major fold its crest is very irregular and is interrupted by numerous minor domes and transverse depressions, which together with irregularities in porosity have been instrumental in segregating the pools.

7. With one exception the best collection of oil was found over the broad flat areas. The domes over the entire field are logical gas reservoirs but contrary to expectation the largest amounts of gas and oil do not lie at the apexes of the domes but a short distance below.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE ABNORMAL TEMPERATURES ON THE COMSTOCK LODE.

Sir: In the late seventies, according to Church, the air issuing from the Comstock mines had a temperature of 92° F. The increase of rock-temperature is one degree for about 30 feet of depth. The bottom levels have yielded water as hot as 170°.

As to the source of the abnormal part of the heat, the prominent possibilities are as follows:

1. Rock-decomposition, particularly hydration. (Church.)
2. The volcanic wall rocks of the lode.
3. Hot springs ascending on the lode. (Becker.)[1]
4. The friction of the lode-faulting.

THE SIGNIFICANT DATA.

To get significant data of the underground temperatures is, as Becker points out, a difficult matter; for these temperatures are deranged by the presence of the mine workings which make possible the presence of the observer. Moreover, evidence, to be at all conclusive, must be both abundant and well studied. Thus, the instances cited by Church regarding the rise in rock-temperatures after the advent of water are valueless as proof of the generation of heat by hydration, because the incoming water was

[1] G. F. Becker, Monograph 13, U. S. Geol. Survey, 1888.

itself hot. And again, the doubtful conclusion to which some of Becker's observations pointed—namely, that the water was hotter than the rock—could not be accepted, even were it well supported, as a final argument that the water was, in general, the source of the heat; for water constantly drawn from the interior and uncooled portions of a rock-mass, must, in any event, have been hotter than those portions of the rock-mass which were accessible to the observer, and which were, therefore, almost certainly cooled.

The unquestionable, pertinent facts are these:

1. At or near the lode, the temperature varies directly with depth.

2. Along the Sutro tunnel[1] the temperature varies with the nearness of the lode and is largely independent of the depth below the surface.

3. The circulation of water within the lode is eccentric: generally, a given locality has been sealed off from others by clay seams, the cutting of which has occasioned serious floods.

4. The water found in the upper levels was cold.

5. Rock and water were almost everywhere nearly the same temperature.

6. Water in large quantities occurred at shallow depths.

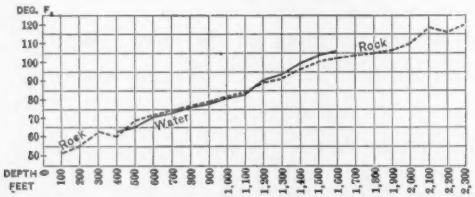


FIG. 75. Temperatures in Foreman Shaft (After Becker)

7. The croppings have never yielded springs of any considerable size.

8. After the emptying of a given level, the level was dry, un-

[1] The tunnel cuts the lode 20,000 feet in and 1,600 feet below the croppings.

less a clay seam of the sort mentioned above was cut. In the interval between the cessation of pumping operations and their resumption (from the early '80's to 1899) the water level stood ten to fifteen feet below the tunnel level in the C. & C. shaft, and the flow from the tunnel was normally between eleven and thirteen miners' inches, though, during the spring, and at times during the winter, it was somewhat more than this. (This information was furnished by Mr. F. O. Broili, superintendent of the tunnel.)

THE FIRST TWO HYPOTHESES AS TO THE SOURCE OF THE HEAT.

That the temperature along the line of the Sutro tunnel varies with the nearness of the lode, necessitates the conclusion that the heat, or, at least, its abnormal increment, emanates from the lode-locality, effectually disposing of the possibility that it is a relic of the volcanic heat of the wall rocks.

The other three hypotheses are thoroughly harmonious with this conclusion. But the hypothesis of Church is no more than a conjecture, devoid of supporting evidence. Moreover, experiments by Barus, recorded in Becker's monograph, indicate that, under the conditions existing on the Comstock, the rocks do not liberate heat by hydration.

THE HYPOTHESES OF HOT SPRINGS AND FAULT-FRICTION.

Of the two remaining hypotheses, Becker's has received by far the greater consideration, and, altogether, it is the one which appeals the more immediately to the attention; for hot springs are abundant in this part of Nevada.

If the heat is actually derived from hot springs, however, these springs possess some remarkable characteristics. First, they have an exceedingly feeble flow—so feeble, that once the water level was brought down below that of the Sutro tunnel, it never later rose to that level, even after pumping had ceased: and again, so feeble, that the water of the upper levels has always been cold. In the second place, the springs must have a very restricted circulation; for the several bodies of hot water exist, we may say,

in several vessels, lacking communication with each other. Nevertheless, the temperature change from point to point adheres to a fairly smooth curve. Still again, the water is feebly mineralized, and contains no ingredient which might not perfectly well have been derived from the solution of the lode materials. True it is that Becker mentions an instance of the evolution of H_2S from water struck in a certain deep level. But this instance is poorly authenticated, and its absolute solitude argues against

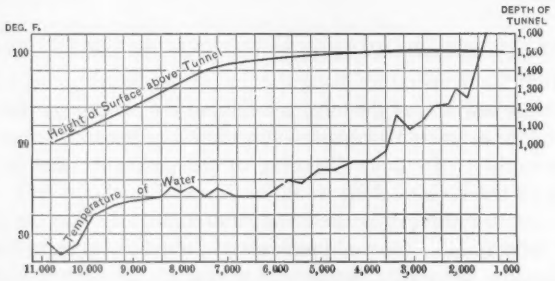


FIG. 76. Sutro Tunnel; Water Temperatures. (Adapted from Becker)

it. Lastly, the water and the materials containing it are of almost identical temperatures. Did the containing materials derive their heat from hot water ascending in any considerable volume, it would seem likely that, at least near the surface, they would lag considerably behind the water in temperature.

We are reduced, then, to two possibilities—either the heat is derived from water of exceedingly slow upward movement, or from the containing materials. I have a slight leaning, which, I must confess, is nothing more than a prejudice, in favor of the second.

But the acceptance of either of these possibilities, and, especially the acceptance of an hypothesis of any detailed source of heat under the second of them, is more difficult than the rejection of all the others. The lode fault has a dip throw of something like a mile, and so, no doubt, generated abundant heat. Yet, later, occurred the lode formation, with the accession to the lode

Analysis of Water from Steamboat Springs, Nevada.[1] Grams per Liter.		Analysis of Water from 2,250-foot Level of C. & C. Shaft, Comstock Lode.[2] Grams per Liter.
SiO_2	0.31065	0.1334
CO_2	.17759	.0150
B_2O_3	.21741	
SO_3	.10389	.3957
S_2O_3	.00307	
S combined as RHS	.00327	
H_2S	.00055	
S	.00052	
Cl	.95243	.0190
Sb_2O_3	.00051	
As_2O_3	.00357	
P_2O_5	.00063	
HgS	trace	
Al_2O_3	.00025	.0025
FeO	.00018	
Fe_2O_3		.0091
CaO	.00958	.1404
MgO	.00047	.0097
Na_2O	.91929	.1765
Li_2O	.01541	
K_2O	.12460	.0643
Cs_2O, Rb_2O	trace	
Total solids	2.84387	.9656

locality of enormous quantities of lode materials, hot at the time of their deposition. Still later, occurred the movement within the lode which produced the well-known "sugar quartz." And we must remember that Church considered only one of the possible heat-producing chemical reactions, and that a very recent one. Perhaps, after all, the now apparently imprisoned hot water may have come in with the lode materials themselves, in which case the ultimate source of its present heat may still have been fault friction.

AUGUSTUS LOCKE.

[1] G. F. Becker, Monograph 13, U. S. Geol. Survey, 1888.

[2] J. A. Reid, Bulletin of the Department of Geology, University of California, Vol. 4, 1905. Analysis by N. E. Wilson.

THE SPECIFIC GRAVITY OF MIXTURES.

Two recent numbers of ECONOMIC GEOLOGY contain articles in each of which a considerable number of computations appear to be based on a false assumption.

If I do not mistake their meaning the authors in each case calculate the average specific gravity of a mixture of minerals by multiplying the specific gravity of each mineral by its percentage weight, and then dividing the sum of the products by 100. It is evident that the volume should be used as a multiplier instead of the weight, as the product of weight by density is an irrational expression, and not itself a weight.

Thus, in Vol. VII., No. 2, pages 174 and 175, C. Zapffe, in discussing Lake Superior iron formations, says:

"According to the characteristics of the mineral as observed under the microscope a certain specific gravity was assigned to it; multiplying this by the percentage volume occupied by the mineral on the slide the percentage of weight was obtained. *The sum of the numbers obtained by multiplying the percentage by weight of a mineral by its specific gravity gives the mineral specific gravity of the formation* in question."

Again, Bateman and Ferguson, in a study of tin deposits (Vol. VII., No. 3, page 238) state:

"The weight of a given volume may be determined from the specific gravity. Unfortunately . . . no specific gravity determinations were given with the analyses. *Hence it is necessary to obtain a value for the specific gravity by calculating the mineral composition from the analysis and multiplying the percentage weight of each mineral by its specific gravity.* The composition of a hundred cubic centimeters of the rock is then obtained by multiplying each component of the chemical analysis by the calculated specific gravity."

Thus Zapffe (taking Table III., page 176, as an example) has evidently calculated the percentage weight of each mineral as

$$\frac{\text{Per cent. volume} \times \text{spec. grav.} \times 100}{\text{Sum of products of percentage volume} \times \text{spec. grav.}}$$

which is of course correct, but has then gone on to compute the general specific gravity as

$$\frac{\text{Sum of products of percentage weight} \times \text{spec. grav.}}{100}$$

which in the case of Table III. gives a value of 3.771.

But the true general specific gravity of the formation is correctly given by the expression:

$$\frac{\text{Sum of products of percentage volume} \times \text{spec. grav.}}{100}$$

which in this particular case has a value of 3.485.

The discrepancy between the values thus found of course increases with the differences in specific gravity of the more plentiful minerals.

Similarly Bateman and Ferguson, starting with percentage weights, obtain in the case of the second table on page 239 a calculated specific gravity of 2.961. If the relative volume of each constituent mineral had first been computed, or the volume per 100 grams of rock, and the sum of the latter volumes been used as a divisor for 100 grams, the result would have been the true specific gravity of about 2.88.

If W be the weight in grams, V the volume in cubic centimeters, and D the specific gravity of a mass of rock made up of individual minerals, whose respective weights are w', w'', w''', etc., their volumes v', v'', v''', etc., and specific gravities d', d'', d''', etc., we have a series of equations

$$W = w' + w'' + w''' + \cdots,$$

$$V = \frac{W}{D} = v' + v'' + v''' + \cdots = \frac{w'}{d'} + \frac{w''}{d''} + \frac{w'''}{d'''} + \cdots,$$

$$W = VD = v'd' + v''d'' + v'''d''' + \cdots.$$

If we make v', v'', etc., *percentage volumes* (*i. e.*, $V = 100$ *cubic centimeters*) we have

$$D = \frac{v'd' + v''d'' + v'''d''' + \cdots}{100},$$

an equation applicable to the first table mentioned.

If, on the other hand, we have to start with values of w', w'', etc., *percentages by weight* (*i. e.*, W = 100 *grams*) we have

$$D = \frac{100}{\frac{w'}{d'} + \frac{w''}{d''} + \frac{w'''}{d'''} + \cdots},$$

applicable to the second table quoted.

In no case can the expression

$$D = \frac{w'd' + w''d'' + w'''d''' + \cdots}{W}$$

afford more than a rough approximation to the true average specific gravity of the mixture, unless the individual minerals differ but slightly among themselves.

My only excuse for pursuing the subject so far is the frequency with which a similar error is made in computations of this character, notably in attempting to calculate the value of nuggets or specimens of native gold mixed with quartz, and of mixtures of coal and slate, by methods based on a determination of specific gravity. A consideration of a gold specimen of exactly one cubic centimeter volume, one half the bulk quartz (sp. gr. 2.60) and one half native gold (sp. gr. 18.20), usually makes the fallacy obvious, the gold forming half the volume and seven eighths of the weight of the mass.

W. J. SHARWOOD.

RECENT DEVELOPMENTS AT LEADVILLE, COLO.

Sir: I was glad to read in a recent issue of ECONOMIC GEOLOGY (Vol. VII., No. 4) the article by Professor Butler on the most profitable fissure vein in the Leadville District, although disagreeing with some of his conclusions.

The knowledge of the existence of these fissure veins is not so recent as Professor Butler states. In 1889–90 I drew the attention of the late S. F. Emmons to such as I had already developed on Iowa Gulch 2 miles southward from the New Monarch-Luema vein described by Professor Butler, one of which is undoubtedly in the same fissure; on Iowa Gulch it is probably the Clear Grit vein in the Union fault.

All the region eastward from the Mike fault produces gold and copper in addition to silver, lead, and zinc, both in the replacement deposits and in the fault fissures, and in the case of the latter the ore is deposited *in situ* as a true fissure vein, not merely "dragged ore" or fragments from the replacement deposits formed at the contacts of the limestones and porphyries.

These facts suggested the theory that in this portion of the Leadville district mineralization occurred distinct from and later than that which formed the contact deposits, and in which the solutions carried gold and copper as their chief metallic elements. These solutions came from below upwards and circulating through the faults and other fissures enriched the preëxisting silver-lead-zinc deposits wherever such were reached. The exceedingly rich gold deposits in the Ibex or Little Johnny and other properties are thus accounted for by a *late enrichment* but not a *secondary enrichment* as ordinarily understood. Mr. Emmons could not accept this view, but he did not personally visit the workings on which I base the theory, with the exception of those in the Ibex property, in which the gold-bearing fissure veins are clearly seen to enter and penetrate the older contacts or limestone replacement deposits.

A short paper on "The Genesis of the Leadville Ore Deposits" in Vol. XLI. of the *Trans. Am. Inst. M.E.* by Mr. Max Boehmer contains a generalized section through the Ibex property well illustrative of Professor Butler's conclusions, and in agreement with him as to the single period of mineralization, but the facts on the ground show that the so-called "post-mineral" faults are actually ore-bearing veins deposited subsequent to the main faulting of the District.

There is no reason to doubt that the Luema vein is but one of a series or system which will be opened and worked profitably. In fact in the Iowa Gulch region before mentioned, no less than four have been worked intermittently for 30 years, and in an examination of the Ibex property made in 1904 no less than six fissure veins were distinguished all lying west of and approximately parallel to the New Monarch-Luema vein.

In Iowa Gulch there is an extrusion of porphyry apparently in the form of a "stock" which has extended southward in the Weston fault for a long distance and probably also northward in a similar manner. This is a mineralized, sheeted zone, similar to the vein described by Professor Butler, and either it or that in the Union fault may be the southern extension of the New Monarch-Luema. I am inclined to believe the latter is the true extension as the Union fault certainly crosses the Weston fault instead of ending at the intersection, as shown by Emmons.

Professor Butler's statement that the material between the fault walls is not a decomposed porphyry dyke, as heretofore generally believed, but is "country rock" is not conclusive; the mass of "kaolin and quartz" at the 450 ft. level would indicate an original porphyry rather than limestone, quartzite or granite, which form the principal portion of the country immediately adjacent to the vein.

CHAS. J. MOORE.

THE CORO-CORO, BOLIVIA, DEPOSITS.

Sir: The paper of Waldemar Lindgren in the September (1911) issue of ECONOMIC GEOLOGY refers to the Coro-Coro (Bolivia) deposits.

These deposits have been worked continuously since 1873 and have yielded about 200,000,000 pounds of copper.

The presence of "silver, domeykite and chalcocite" is of rare occurrence; specimens are limited in number. The copper concentrates (locally called "Barrilla") carry neither silver nor gold of economic value.

The origin of the deposits as explained by Steinmann (the original paper is not at hand) does not appear applicable. There are no diorite intrusions in the deposits (the nearest being about 12 miles distant) or immediate formation which has suffered considerable movement and faulting. At first sight the copper appears to have been deposited contemporaneous with the sandstone but a closer study indicates the deposition to have occurred through chemical reactions between copper solutions and calcium (chiefly gypsum which is widely distributed in the deposits), iron and sodium salts and appearing as filling of intergranular spaces (from minute grains to the size of buck shot) or masses of copper containing quartz grains. Secondary enrichment is responsible for the masses or sheets of almost pure copper. From outcrops some distance from Coro-Coro a few specimens of native copper and coal have been noted.

LESTER W. STRAUSS.

LIMA, PERU.

THE LLANO–BURNET REGION, TEXAS.

Mr. Edward Steidtmann in ECONOMIC GEOLOGY for June, 1912, reviews a bulletin by the writer, "The Mineral Resources of the Llano-Burnet Region, Texas." Mr. Steidtmann's review is in part misleading. The writer did not "feel the necessity of proving that sedimentary iron ores exist in formations of various periods" as implied by Mr. Steidtmann, but used this fact to show the inherent probability that sedimentary iron ores are likely to occur in pre-Cambrian rocks. This was only one of several arguments (ignored by Mr. Steidtmann) to establish the conclusion that the ores were in large part of sedimentary origin. Mr. Steidtmann ignores the geologic relations of the ores, the characteristics of the ores, the bearing of igneous rocks of the region on the origin of the ores, the chemical relations, the probable conditions at the time of intrusion, and the comparison with

other regions,—all of which subheadings are of equal weight with that to which reference is made by the reviewer.

Much of the "surpassing" tonnage of low phosphorus ore of the Lake Superior Region referred to by Mr. Steidtmann is considered by those who have given the subject most attention as reconcentrated ore and was therefore properly and purposely left out of the discussion by the writer.

SIDNEY PAIGE.

REVIEWS

The Geology of the Lake Superior Region. By C. R. VAN HISE AND C. K. LEITH. Monograph LII., U. S. Geological Survey, 1911, 4to, pp. 641, pls. XLIX., figs. 76.

The monograph on the Lake Superior region as a whole will meet a warm welcome not alone from geologists and those interested in the purely scientific side, but from the workers in the great mining industries for iron and copper, whose districts are passed in review. The book is a summary of many years of careful observation, and we may regard it as the fruition not alone of the work done under the U. S. Geological Survey, but also of the earnest efforts of the early pioneers, Houghton, Foster and Whitney; of the later group embracing the Winchells of two generations, Brooks and his colleagues, of Wadsworth, Hubbard, Lane, Spurr, Lawson, Coleman, Seaman, and many others, to whom the authors make frequent reference and acknowledgments. Special gratification will be felt by the reader who recalls with a smile that the C. R. Van Hise of the early eighties boarded a railway train after his first summer's struggles with the gnats, black flies, mosquitoes, burned tracts, second growths, and puzzling geology in the Marquette Range, thanking his stars that the work was over and that he would never be foolish enough to go back. Thus it is with all geologists worth their salt. The hardships often reach the limit of endurance, but the observer with a mission is never content until after a respite, he has gone back and completed his task.

The monograph will be especially welcome to those university instructors who annually carry their graduate students over the methods, philosophy and results of study in the Precambrian, and who have found, as has the reviewer, that six great volumes on the iron districts and a seventh on the copper-bearing rocks are more than a student, however earnest, can read and digest. The multitude of details bewilders and the essential becomes obscured.

After acknowledgments to those who have assisted in the preparation of the book, outlines of geographical and other features, the monograph proper opens with an historical review of the development of mining in the Lake Superior region. The review covers copper and iron, since these industries together with lumbering have chiefly brought

settlers into the region. Elaborate and detailed statistics are given together with a very complete bibliography. The physical geography is then discussed by Lawrence Martin, who toward the close of the work deals also with the Pleistocene. The prominence of the Precambrian problems and the interest attaching to the ores should not lead us to overlook the importance of the peneplains, monadnocks, ancient shore lines, and of the great depression of Lake Superior itself. The mining districts for iron are next reviewed by the two principal authors. Canadian as well as American localities are summarized and illustrated by maps and sections. The individual features of the ores and ore-bodies are especially commented upon and many suggestive points are made regarding porosity and capacity to absorb moisture; regarding constituent minerals in quantitative relations; likenesses and differences in districts; comparisons between parent rock and derived ore, etc.; all of which show how one thing has led to another and how problem after problem has come up in estimating and mining the ores. Not a few new points are here which one misses in the older monographs. The authors have constantly employed with great success, the triangular diagrams which so graphically illustrate the variations of three quantities. They have also followed up the phosphorus of the ore to its probable source. Many readers will be surprised to learn that it relatively increases in the change from cherty carbonates to ore, and at times, to such a degree in Minnesota, as to lead the authors to infer contributions from Cretaceous strata, which though now gone, may once have covered the Mesabi range.

In the review of the various ranges Canadian and American the authors lay the foundations for the discussion of the difficult problem of the original precipitation of the cherty carbonates which comes up for subsequent treatment in connection with the formation of the ore-bodies. In the elaboration of details the authors appreciatively credit valuable aid to W. J. Mead and several other younger helpers.

The Keweenawan next comes in for review and treatment. Readers not personally familiar with this formation in the Lake Superior region will have brought forcibly home to them the great amount of sediments in the lower and upper divisions. The prominence of the copper in the eruptives and minor sediments of the middle division have often led to the impression that the formation was almost entirely lavas. The sediments, especially, in the upper portion are necessarily the chief clues by which we may explain the puzzling relations with the Upper Cambrian or supposed Upper Cambrian. The authors conclude that the Keweenawan is certainly pre-Upper Cambrian and that it probably is older than the Middle and Lower Cambrian, but that its upper portion may have been in process of deposition, when the progressive overlap of the Paleo-

zoic spread Upper Cambrian across it. Much study has also been given by many earlier observers, to the petrography of the Keweenawan igneous rocks and some differences of nomenclature have crept in. A. N. Winchell summarizes and tabulates these, with many suggestive comments.

Following the chapters on the Keweenawan, as stated above, Lawrence Martin reviews the Pleistocene history of the region and in his treatment epitomizes and interprets the extensive literature upon these closing features of geological history. The condensed statement will be very serviceable to students in this field.

In Chapters XVII. and XVIII., treating respectively of the formation of the iron ores and of the copper, readers of ECONOMIC GEOLOGY will find the portions of the monograph which are for them of altogether exceptional interest. With the help of W. J. Mead the authors first pass the iron ores in review. The main features of occurrence, as one meets the ores in the field, the associated strata, the practical bearing of physical properties, exploration, reserves and methods of shipment are all discussed. When, however, we come to the geological problem involved in explaining the vast deposits of siliceous carbonates we find much matter that is new and of extraordinary interest. After estimating the respective claims of all manner of methods of deposition, the authors conclude that the beds are essentially sedimentary, but are so peculiar as to demand unusual conditions. It is necessary to establish such conditions as will make possible the precipitation of ferrous silicate and ferrous carbonate in the presence of vast quantities of silica. Obviously, the chemical conditions must be neutral or reducing. The authors are led to the great volcanic outbreaks of the Keewatin and of the middle and upper Huronian as the source of the iron and silica, and to the action of heated oceanic waters upon submarine flows and to extensive contributions of magmatic waters as the main sources. Ordinary erosion and weathering have contributed in only a minor way to the cherty carbonates and the associated ores. Some extremely important experiments have been carried out in the laboratory by M. E. Diemer and others, within conditions set by the authors, and the reactions and results contribute in the strongest manner to establishing the soundness of the explanations briefly outlined above. The thoroughness with which observations have been recorded in the field, tested in the laboratory, checked by wide reading and comparison with results elsewhere cannot be too highly commended. They elaborate and demonstrate what had been less firmly established. Yet one or two things come back to a reader with great force, such as the acuteness and importance of the observations of J. E. Spurr when he first detected what he called glauconite in the Minnesota cherty carbonates; and the similar

importance of the interpretations of N. H. and H. V. Winchell of the Keewatin cherty carbonates, as far back as 1889. The Winchells advocated an origin by chemical precipitation, made possible by the reactions of hot lava flows and marine waters. It is of much interest to note that these half-forgotten suggestions are so fully corroborated by the later work.

Once precipitated as stratified beds the cherty carbonates, richer in iron in some places than in others, became cracked and broken by the geological disturbances to which the region was subjected. Oxidation, rearrangements, removal of silica, concentration and recrystallization to grunerite-magnetite schists by contact metamorphism, all took place. The processes are followed out in detail in the monograph. As is so generally the case in mining experience, and as holds true also for the copper, we see that ore has developed where rocks were open textured and permeable. Ore fails on the other hand where the rocks are tight, hard and resistant.

In the discussion of the copper deposits views are set forth of no less interest than those elaborated under iron. No greater puzzle has ever been afforded to mining geologists than the problem of Lake Superior copper. The recent observations of A. C. Lane on the mine waters, and the experiments of G. Fernekes with copper chlorides have been of much suggestiveness. Our authors are more in sympathy with the views of H. L. Smyth than with those of the majority of earlier writers, and finally conclude that the copper was largely precipitated by magmatic waters in the cooling stages of the igneous outbreaks. They emphasize the association of large copper deposits with large sheets of basaltic rock, refer the metal to an original home in the neighboring mass and show that the precipitation has gone on where neighboring rock was open-textured and amenable to the influence of solutions. As one reflects on the exceptional nature of the problem and its difficulties, one cannot but feel that there is much sound reason in these views.

A brief chapter on the gold and silver deposits of the region and a more extensive one in review of the whole problem of the geological development, conclude the work.

Again, congratulations may be extended to the authors and their associates on the issue of so important and so useful a monograph. Rarely does it fall to two writers, to summarize so much of earnest and successful effort. The pages bring out the progress of years and the changing view points with great force. If, for example, a reader will turn to the *Transactions of the American Institute of Mining Engi-*

neers, XXX., 47, 1900, and read the paragraph on "The Source of the Underground Water," he will feel the force of Pope's lines,

> "Manners with fortunes, humors turn with climes,
> Tenets with books and principles with times."

J. F. KEMP.

The Examination of Prospects, A Mining Geology. By C. GODFREY GUNTHER, E.M. McGraw-Hill Book Company, New York and London, 1912. 222 pp., soft leather binding, pocket size (5 by 7 inches), $2.00.

If we may judge from its pocket size and from its flexible leather cover, as well as from its main title "The Examination of Prospects" this little book was intended primarily for the field guidance of mining engineers and students of mining geology. It will fill this field most usefully but it is a pleasure to record that the book is not a compendium of rule-of-thumb methods which such pocket manuals often prove to be, but is what its second title indicates, "A Mining Geology." It is, moreover, in the reviewer's opinion, the best elementary treatise on the geology of metalliferous deposits that has yet been published, and this rather sweeping commendation may justify the length of the following review.

The choice of subject matter, arrangement, clearness and simplicity of style are what would be expected in an elementary text-book for college use and recommend it to the serious attention of teachers of geology. To quote from the preface:

"The purpose of this book is to present the practical side of economic geology concisely and in convenient form; established facts and the applications of accepted views are emphasized; theoretical discussions and questions of genesis are avoided. Coal, iron, and placer deposits are omitted; they are subjects of specialized study that are fully and concisely treated in other works. The reader is assumed to possess a knowledge of mineralogy, petrography, and of elementary geology."

The plan of treatment is based upon generally accepted principles of structure and genesis, individual mining districts being referred to only to exemplify the principles set forth. The seventy-nine figures which illustrate the book have been discriminatingly selected and are largely taken from the reports of the U. S. Geological Survey.

Chapter I. includes a discussion of the purpose of the examination of mining properties and it is appropriately pointed out that the objects sought and the methods used are not the same in all cases, as for example, in the case of a prospect versus a developed mine. Such

matters as terms of sale and perfection of title are touched upon and mine sampling is treated briefly but effectively with many warnings against salting, advanced preparation of the mine for examination, and other pitfalls for the unwary examiner.

In Chapter II. faults, folds, and other structural features commonly met with in association with ore deposits are defined. Commendable emphasis is laid upon the study of surface exposures which in many cases furnish the only complete geologic section available.

Chapter III. is devoted to a description of the different types of ore deposits considered principally from the structural standpoint. The framing of definitions in a field where terms have often been loosely applied is a matter of difficulty, but those given by the author are in general in harmony with the most modern usage.

In Chapter IV. the importance of the mineral composition of primary ores as a key to the conditions of depth under which they were formed is especially emphasized. A table is given of the more important ore and gangue minerals which may be of critical value as indicators of primary origin on the one hand or of secondary origin on the other.

Chapter V. is devoted to a discussion of the principal types of ore deposits considered largely from the genetic standpoint, sections being devoted to magmatic segregations, contact deposits, pegmatitic deposits, fahlbands, regionally metamorphosed ore deposits, deposits due to the filling of open spaces, replacement veins, other replacement deposits, disseminated mineralizations, mineralized conglomerates of uncertain origin, and bedded deposits. The classification used is not intended to be strictly genetic or all inclusive, but as the author states "is one of convenience only" to differentiate the most important and best defined types.

In Chapter VI. are discussed the various factors, structural and chemical, which determine the form of primary ore shoots. In Chapters VII. and VIII. the various types of primary and surface alteration of wall rocks are summarized. Chapter IX. is devoted to a short discussion of residual ores. Chapter X. discusses the criteria which may be used for the recognition of ore deposits of secondary origin, the characteristic forms of such deposits, and their relation to the surface and to the groundwater level. In Chapter XI. the outcrops of ore bodies are treated.

EDSON S. BASTIN.

The Natural History of Clay. By ALFRED B. SEARLE. Cambridge: at the University Press; New York: G. P. Putnam's Sons, 1912. 40 cents net.

A brief, elementary but comprehensive treatise on clay bearing the above title forms a valuable addition to "The Cambridge Manuals of Science and Literature."

The method of treatment is conservative, the work being a digest of existing knowledge and theory rather than a contribution of new ideas. The author is a master of his subject. He does not attempt to define clay, though he emphasizes the point that it is not a mineral but a rock of indefinite composition; yet he uses such expressions as "true clay" and "pure clay substance."

The first or introductory chapter treats the chemical and physical properties of clays. The discussion of chemical properties relates principally to impurities—(*a*) gravel and sand (*b*) quartz, feldspar, mica and other silicates, (*c*) lime, magnesia, iron, potash, soda, carbon, water, and other oxides, sulphides, sulphates and carbonates. The physical properties dwelt upon at some length are first of all plasticity, numerous ideas concerning which are referred to, binding power, shrinkage, fusibility, and refractoriness, vitrification, porosity, absorptive and adsorptive powers, and the effect of heat and exposure to weather.

The second chapter entitled "Clay and Associated Rocks" is largely a geological description of clays beginning with the oldest rocks and extending down to the most recent. Here as elsewhere in the book and in other English works statements applying to the British Isles only are made without appropriate qualification.

The third chapter deals with the "Origins of Clays" and the fourth with the "Modes of Accumulation." Aside from residual clay three kinds of primary clay are recognized: (1) kaolinic or china clay derived chiefly from feldspar; highly refractory and slightly plastic (2) epigenic or colloidal clay—a secondary product from kaolinic clays or derived directly from alumino-silicate minerals by weathering; of medium plasticity and refractoriness, and containing a large percentage of impurities, (3) lateritic or highly aluminous clays, such as bauxite; very refractory, but not very plastic, completely decomposed by hydrochloric acid. Secondary clays or pelinites are extremely variable and their essential constituent is not known with certainty. Under "Accumulation of Clays" are considered transportation, separation, and sedimentation, including precipitation and redeposition.

In the fifth chapter, bearing the title "Some Clays of Commercial Importance," the characters of workable clays and shales and the requirements for various purposes are described.

The sixth chapter bears the title "Clay Substance: Theoretical and Actual." It is largely a review of the discussion of this subject. The chapter closes with a classification of clays which is a modification of Grimsley's and Grout's classification, as follows:

I. Primary clays:
- (*a*) Clays produced by weathering silicates—as some kaolins.
- (*b*) Clays produced by lateritic action—very rich in alumina, some of which is apparently in a free state.
- (*c*) Clays produced by telluric water containing active gases (hypogenically formed clays)—as cornish china clay.

II. Secondary clays:
- (*d*) Refractory secondary clays—as fireclays and some pipe clays.
- (*e*) Pale burning non-refractory clays—as pottery clays, ball clays, and some shales.
- (*f*) Vitrifiable clays—as stoneware clays and paving brick clays.
- (*g*) Red burning and non-refractory clays—as brick and terra-cotta clays and shales.
- (*h*) Calcareous clays or marls, including all clays containing more than 5 per cent. of calcium carbonate.

III. Residual clays:
- (*i*) Clays which have been formed by one of the foregoing actions and have been deposited along with calcareous or other matter but on the latter being removed by subsequent solution, the clay has remained behind.

There is some repetition of matter in the book, and here and there a statement as to the agricultural value of a clay is given although the relation of clays to agriculture is not otherwise discussed. There are a few typographical and perhaps other errors, as for example the statement on page 62 that "The Tertiary clays include all those deposited after the chalk and previous to the *close* of the glacial period." But, nevertheless, the work will no doubt prove to be a handy little reference volume.

E. W. SHAW.

Reconnaissance of the Jarbidge, Contact and Elk Mountain Mining Districts, Nevada. By F. C. SCHRADER. Bull. U. S. Geological Survey, No. 497. Pp. 162 with maps, sections, and illustrations. 1912.

Geography.—The [Jarbidge, Contact and Elk Mountain] districts are in Elko County in northeastern Nevada near the Idaho State line. They are contained in an east-west rectangular area about 35 miles long by 26 miles wide, the Jarbidge district being in the western part, the

Contact district in the eastern part and the Elk Mountain district in the northern part. Geologically and mineralogically the Elk Mountain district is a small scale replica of the Contact district.

The area is about 50 miles distant from the Twin Falls Branch of the Oregon Short Line Railroad on the north and from the Southern Pacific Railroad on the south. It lies in the northeastern part of the upland region known as the Nevada Plateau. It is mainly on the southern rim of the Snake River drainage basin, whence it extends across the divide and includes a small part of the adjacent Great Basin on the south. It lies at the general elevation of about 6,000 feet, but it is mostly mountainous and has a vertical range of nearly 6,000 feet and culminates at about 11,000 feet in the Jarbidge Mountains on the west. In the western part the drainage issues northward through the Bruneau River and in the eastern part eastward, thence northward through the Salmon River, both rivers being main south side tributaries of the Snake. .

Geology.—The area is in a region of fundamentally Paleozoic sedimentary rocks seeming carboniferous. They consist principally of quartzite, limestone, shale and slate, and are folded, faulted, intruded by Cretaceous? granodiorite flooded and capped by Tertiary eruptives, principally rhyolite, and overlain by Tertiary lake beds and Quaternary gravel and alluvium.

In the Jarbidge district the rocks are principally rhyolites. Here the Paleozoic sediments are exposed only on the west. They consist, in ascending order, of quartzite, limestone and shale aggregating about 3,000 feet? in thickness and they dip steeply to the north. The rhyolites are separable into two distinct groups, old rhyolite of Miocene? age and young rhyolite, Pliocene. Each group consists of a series of superimposed flows.

The old rhyolite occupies a central area about 8 miles square, has a thickness of nearly 5,000 feet, and is the principal ore-bearing rock. Its flows are heavy, ill-defined and lie nearly horizontal. It is gently folded, faulted and considerably fissured. It is coarse-textured, with large phenocrysts of wine-colored quartz and feldspar.

The young rhyolite surrounds the old rhyolite with wide extent. It has a maximum thickness of nearly 2,000 feet. It is non-ore bearing and but little disturbed. Its flows are relatively thin, well banded and dip gently outward. It is lithoidal or aphanitic with little or no visible quartz, the silica occurring mainly in the form of tridymite.

The principal rocks of the Contact district are the granodiorite and the Paleozoic sediments which it intrudes. The granodiorite occupies a central elongated quaversal east-west batholitic belt 25 miles long by 6 miles wide. Surrounding it in a belt several miles in width succeeds the overlying quaquiversally outward dipping Paleozoic sediments with

a known thickness of about 1,600 feet. They are considerably contact metamorphosed by the magmatic intrusion of the granodiorite and both they and the granodiorite are intruded by complementary syenitic, aplitic, lamprophyric and monzonite dikes. The rhyolite which occurs chiefly peripherally, corresponds to the young rhyolite of the Jarbidge district with which it seems to be continuous. The old rhyolite of that district seems to thin and peter out on the western headwaters of the Salmon and does not appear in the Contact district.

The Tertiary lake beds of the area occur chiefly in low places in the Contact district where they have a known thickness of 400 feet. They are mainly gray "sandstone" composed of volcanic tuff which is chiefly pumiceous. In places they are tilted, flexed and gently folded. They seem to be of Pliocene age and belong to the Humboldt formation.

The Quaternary deposits of the area besides recent stream gravels, debris and wash from the hills, include in the Jarbidge Mountains, also some glacial accumulations of Pleistocene age.

Ore Deposits.—The ores were deposited in at least two distinct periods of mineralization, Cretaceous? and post-Miocene.

The Cretaceous deposits are chiefly auriferous and argentiferous copper ores. They occur mainly in the Contact district and consist principally of contact metamorphic deposits conforming to the contact zone of the granodiorite with the Paleozoic sedimentaries, and deposits in fissures. The contact metamorphic deposits contain much axinite, indicating that pneumatolitic action was an important agency in their origin. The fissure deposits are associated with the complementary dikes and contemporaneous or slightly later quartz veins, and include replacement bodies in the wallrock. They occur principally in the granodiorite. The fissures have a steep southerly dip.

The post Miocene deposits are argentiferous gold ores. They occur in quartz-adularia fissure veins in the old rhyolite in the Jarbidge district. They were discovered late in 1909. The fissures are mostly contained in two main systems which converge downward. Those of the west system dip steeply to the east and those of the east system dip steeply to the west. The gangue is pseudomorphic after calcite and rhyolite and was deposited by ascending thermal solutions that dissolved out and replaced the earlier calcite gangue.

FRANK C. SCHRADER.

Introduction to the Study of Minerals. By AUSTIN F. ROGERS, Associate Professor of Mineralogy and Petrography, Leland Stanford Jr. University. McGraw-Hill Book Company, 239 West 39th St., New York.

This work was undertaken with a two-fold mission in view: to furnish

a text book for a one year course in mineralogy, and at the same time serve as a pocket manual for field work. The book, which in the main, follows the same general order of treatment as other standard texts, contains however several distinctive features such as a description of the optical properties of crushed fragments, determinative tables, a list of occurrences of minerals pointing out their paragenesis and a glossary of terms.

The subject matter is discussed conveniently under eight subdivisions, dealing (1) with the form of minerals, (2) the physical, (3) the optical, (4) the chemical properties of minerals, (5) the determination of minerals, (6) the description of important minerals, (7) the occurrence, association and origin of minerals and (8) the uses of minerals.

In the portion dealing with crystallography it would seem as if too much had been attempted in the 60 odd pages devoted to this subject. In several instances statements are made without adequate explanation or a diagram to illustrate the point in question. On page 15 the definition of a prism is given as "a form that is parallel to the vertical axis and cuts the other two," while on page 39 we are confronted with a tetragonal prism of the second order with the symbol [100]. In the discussion of the twelve classes of the hexagonal system there seems to be no apparent reason for developing tetartohedrism and ogdohederism before all the hemihedral classes had been disposed of.

The portion dealing with the measurement, projection and drawing of crystals, as well as the chapter on the optical properties of minerals (part III.) have been presented in a clear and concise manner and can readily be used as a basis for more advanced courses in these subjects.

In part IV. a summary of the qualitative chemical tests are given together with the most serviceable blowpipe reactions. The scheme on the whole is adequate but under the "Select Blowpipe and West Tests" (p. 195) the following well-recognized reactions have been omitted: Cassius purple test for gold, ammonium persulphate reaction for manganese, the sulphuric acid tests for molybdenum, the dimethyl glyoxine reaction for nickel, and the hydrogen peroxide test for vanadium.

In the chapter dealing with the determination of minerals (part V.) six tables are inserted based on various physical, chemical, and optical properties. These tables might profitably have been condensed, in all events these tables should follow the descriptive portion (part VI.) and not be inserted before a single mineral had been described.

Two hundred of the more important minerals are described in part VI., where the arrangement is similar to that of Dana. In this division the distribution has not been sufficiently emphasized as no occurrence in the United States is recorded for chalcopyrite, proustite, manganite, strontianite, alunite, wolframite, and zircon, while not a single locality,

here or abroad, is cited for niccolite, allanite, jamesonite, bournonite, ilmenite, pyrargyrite, pyrolusite, scheelite, limonite and talc.

To the student interested in the economic side of mineralogy parts VII. and VIII. will have a special interest. Here stress is placed upon the origin, association, uses, occurrence, treatment, etc., of those minerals which have gained commercial importance. The discussion, though necessarily brief, is excellent.

W. F. HUNST.

WASHINGTON, D. C.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

ADOLPH KNOPF AND J. B. UMPLEBY.

METALLIFEROUS DEPOSITS.

ALUMINUM.

The Production of Bauxite and Aluminum in 1911. By W. C. PHALEN. Advance Chapter from Mineral Resources of the United States. U. S. Geol. Survey, 1912, 19 pp.

The production of bauxite in the United States in 1911 amounted to 155,618 long tons, valued at $750,649. U.

COPPER.

The Geology and Ore Deposits of the Silver Bell Mining District, Arizona. By CHARLES A. STEWART. Bull. Am. Inst. Min. Eng. No. 65, 1912, pp. 455–506.

The ore deposits are of three kinds: cupriferous contact-metamorphic, chalcocitized pyrite disseminated in igneous rocks, and lead-silver veins. The bulk of the production has come from the contact-metamorphic deposits, a production of 11,000,000 pounds of copper being attained in 1909. The ore bodies of this kind consist chiefly of cupriferous pyrite and chalcopyrite in a gangue of andraditic garnet, quartz, calcite, and wollastonite; they are genetically connected with the intrusion of alaskite porphyry and granite into Paleozoic limestone. It is suggested that garnetization took place by a process analogous to pegmatitic injection. A bibliography of contact-metamorphic deposits is appended.

GOLD AND SILVER.

Geology of the Tonopah Mining District. By AUGUSTUS LOCKE. Bull. Am. Inst. Min. Eng. No. 62, 1912, pp. 217–226.

The interpretation of the geologic succession at Tonopah is a matter of economic importance. The writer concludes, with Burgess and against Spurr, that the rocks are a series of superposed flows with intercalated beds of tuff at the contacts whose interpretation has been in dispute.

The Minerals of Tonopah Nevada. By ARTHUR S. EAKLE. Bull. Dept. Geology Univ. California, Vol. 7, No. 1, 1912, 20 pp.

Describes the 45 minerals which have been recognized in the gold-silver deposits at Tonopah and outlines their genesis. U.

Notes on the Northern La Sal Mountains, Grand County, Utah. By J. M. HILL. Bull. U. S. Geol. Survey No. 530–M, 1912, 22 pp.

Gold-quartz veins and gold placers are being prospected.

IRON.

Iron Ores of Marshall and Benton Counties. By E. N. LOWE. Mississippi State Geol. Survey, 1912, 24 pp.

The iron ore consists of beds of iron carbonate in rocks of Eocene age; is believed to be of no little economic importance to the State.

LEAD AND ZINC.

Genesis of Silver-Lead Ores in the Wardner District, Idaho. By OSCAR H. HERSHEY. Min. and Sci. Press., Vol. 104, 1912, pp. 750–753, 786–790, 825–827.

Concludes that the lead, silver, and zinc minerals were originally disseminated in certain bands of the Algonkian sediments and were concentrated through the agency of hot solutions emanating from a monzonite magma.

TIN.

The Tin Lodes of Sandy Creek, Charters Towers District. By W. E. CAMERON. Geol. Survey Queensland, Publi. No. 235, pp. 40–43.

The Tin-mining Industry and the Distribution of Tin Ores in New South Wales. By J. E. CARNE. Min. Res. Dept. of Mines No. 14, Sydney, 1911, 378 pp.

The tin deposits of New South Wales, with a total production of 8,682,000 pounds, are now being extensively exploited by reason of the

high market price of the metal. This report deals with the purely economic aspect of the industry although there are many allusions to the geologic relations of individual deposits. U.

Tin Resources of Alaska. By FRANK L. HESS. Bull. U. S. Geol. Survey No. 520–B, 1912, 6 pp.

A brief outline of the occurrence, recent development, and exploitation of the tin resources.

NON-METALLIC PRODUCTS.

CLAYS.

An Introduction to British Clays, Shales, and Sands. By ALFRED B. SEARLE. Charles Griffin & Company, Limited, London, 1912, 451 pages, with 10 plates and 53 figures.

Treats of the formation, characteristics, physical and chemical properties, mining, technology, and legal position of clays.

Notes on the Clays of Delaware. By G. C. MATSON. **Clays in the Portland Region, Maine.** By F. J. KATY. Bull U. S. Geol. Survey No. 530–I, 1912, 24 pp.

Physiography and Geology of the Coastal Plain Province of Virginia. By W. B. CLARK and others. Charlottesville, 1912, 274 pp.

Forty pages of this publication are devoted to the economic products which consist largely of clay and marls. U.

COAL.

An Investigation of the Coals of Canada With Reference to Their Economic Qualities. In six volumes. Vol. 1 by J. B. PORTER and R. J. DURLEY, Canada Dept. of Mines, Ottawa, 1912, 233 pp.

Describes in the first 105 pages the coal fields of Canada. Later sections are devoted to the collecting of material, sampling, coal washing, and the manufacture and testing of coke. U.

The Black Mountain Coal District, Kentucky. By J. B. DILWORTH. Bull. Am. Inst. Min. Eng. No. 62, 1912, pp. 149–176.

Gives the general geology and structure of the field, the geology and character of the coals, and general correlations with other well-known seams in adjoining fields.

Coal on Dan River, North Carolina. By R. W. STONE. Bull. U. S. Geol. Survey No. 471–B, 1912, 35 pp.

Thin non-persistent lenses of semianthracite occur in Triassic rocks. It is concluded that the field is commercially valueless.

Coals of the Region Drained by the Quicksand Creeks in Breathitt, Floyd, and Knott Counties. By F. JULIUS FOHS. Bull. Kentucky Geol. Survey No. 18, 1912, 79 pp.

Treats of the occurrence of the coals, gives detailed sections, and cites anlyses of some of the coals.

Die Rezenten Kaustobiolithe und ihre Lagerstätten. Band 2: Die Humus Bildungen. (1. Teil) By H. POTONIE. Abhand. König. Preuss. Geol. Landesanstalt, neue folge, heft 55, 11, 1911, 323 pp.

Treats in detail the chemistry and origin of humus, of the formation of peat, and of moors (areas covered by notable deposits of autochthonous humus that have originated under the influence of water which prevented complete decomposition).

Lignite in the Fort Berthold Indian Reservation, North Dakota, North of Missouri River. By MAX A. PISHEL. Bull. U. S. Geol. Survey No. 471–C, 1912, 19 pp.

Lignite beds up to 30 inches in thickness occur in the Fort Union formation of early Eocene age.

Publication No. 235, Geol. Survey of Queensland, contains

1. Coal on the North Ipswich Coal and Coke Company's Property, North Ipswich. By W. E. CAMERON. Pp. 3–6.
2. Coal near Dalby. By W. E. CAMERON. Pp. 7–13.
3. Coal near Chinchilla. By E. O. MARKS. Pp. 14–17.
4. Coal with Glossopteris Flora, near Hughenden. By E. O. MARKS. Pp. 18–20.

GRAPHITE.

Graphite near Raton, New Mexico. By W. T. LEE. Bull. U. S. Geol. Survey No. 530–L, 1912, pp. 3–6.

A large body of amorphous graphite occurs in the Raton field, due to the metamorphism of a coal bed by intrusive sills.

The Production of Graphite in 1911. By EDSON S. BASTIN. Advance Chapter from Mineral Resources of the United States. U. S. Geol. Survey, 1912.

The total production of crystalline-graphite was notably less in 1911 than in 1910, but as in previous years the bulk of it came from New York, Pennsylvania, and Alabama. The production for 1911 was 3,618 short tons, valued at $288,465. U.

OIL AND GAS.

The Dome Theory of the Coastal Plain. By A. F. LUCAS. Science, N. S., Vol. 35, 1912, pp. 961–964.

Denies the claim of G. D. Harris as originator of the dome theory of the accumulation of oil in the gulf coastal plain and brings forward much evidence to show that the credit for the theory belongs solely to A. F. Lucas.

Geologische Beobachtungen aus West Afrika. By RUDOLF ZUBER. Verhandl. k. k. geol. Reichsanstalt, Wien, 1911, pp. 89–106.

Bitumen and petroleum occur locally on the Guinea Coast in Pliocene deposits of Flysch-like character. These deposits were probably laid down under conditions similar to those now obtaining on the Guinea Coast, which are described in detail.

Oil Concentration about Salt Domes. By G. D. HARRIS. Science, N. S., Vol. 35, 1912, p. 546.

The author points out the value of his dome theory for locating oil pools in Louisiana.

PHOSPHATE.

The Production of Phosphate Rock in 1911. By F. B. VAN HORN. Advance Chapter from Mineral Resources of the U. S. U. S. Geol. Survey, 1912, 14 pp.

Florida, Tennessee, South Carolina, Arkansas, Idaho, Wyoming, and Utah all contain productive phosphate fields. In the western States there are estimated to be 2,500,000,000 tons of minable phosphate rock carrying 70 per cent. or more of tricalcium phosphate. U.

ZIRCON.

Zirconiferous Sandstone near Ashland, Virginia. By T. L. WATSON and F. L. HESS. Bull. U. S. Geol. Survey No. 530–P, 1912, 9 pp.

Describe large and hitherto unknown deposits of highly zirconiferous sands of middle Miocene age. The zircons are very small, are water-worn and have been derived from pre-Cambrian granites and gneisses. Zircon makes up as much as 29 per cent. of the sand. It is accompanied by much ilmenite, by garnet (?), cyanite, hercynite (?), rutile, quartz, staurolite, and tourmaline. F. L. H.

SALINES.

Alunite in the San Cristobal Quadrangle, Colorado. By ESPER S. LARSON. Bull. U. S. Geol. Survey No. 530–F, 1912, 7 pp.

Extensive areas of alunitized rhyolite occur, probably due to hot ascending solutions.

Die Physikalisch-chemischen Bedingungen bei der Bildung der Salzlagerstätten und ihre Anwendung auf Geologische Probleme. By SVANTE ARRHENIUS and RICHARD LACHMANN. Geol. Rundschau, Vol. 3, 1912, pp. 139–157.

The salt deposits of the Zechstein were laid down at a temperature below 20° C. (instead of 70° C. as determined by van't Hoff). During the Mesozoic they were buried beneath several kilometers of sediments; this loading induced various internal and external deformations. The intrusive salt plugs (eczemes) are due to local isostatic effects.

Der Untergrund der Lüneburger Heide und die Verteilung ihrer Salzvorkommen. By H. STILLE. Jahresbericht Niedersächs. Geol. Ver. zu Hannover, 1911, pp. 225–286.

WATER RESOURCES.

Surface Water Supply of the U. S. Pt. 5. Hudson Bay and Upper Mississippi River. By R. FOLLANSBEE, A. H. HORTON, and G. C. STEVENS. Water-Supply Paper U. S. Geol. Survey No. 285, 1912, 318 pp. U.

Water Resources of the Penobscot River Basin, Maine. By H. K. BARROWS and C. C. BABB. Water-Supply Paper U. S. Geol. Survey No. 279, 285 pp. U.

REGIONAL.

Florida State Geological Survey, Fourth Ann. Rept. By E. H. SELLARDS. Tallahassee, Fla., 1912, 175 pp. U.

Geological Survey of Jackson, Mason, and Putnam Counties, West Virginia. By CHARLES E. KREBS. Wheeling, 1911, 387 pp.

Describes the geology and mineral resources of the area. U.

The Mineral Production of Canada for the year 1910. By JOHN MCLEISH. Ann. Rept. Dept. of Mines No. 143, Ottawa, 1912, 328 pp.

The total value of the mineral production in Canada in 1910 was $106,823,623, an increase of 16 per cent. over 1909. Of this amount $49,438,873 was derived from metallic products, important among them silver, nickel, gold, and copper. U.

Notes on Mining in Seward Peninsula, Alaska. By PHILIP S. SMITH. Bull. U. S. Geol. Survey No. 520–M, 1912, 8 pp.

A progress report for the year 1911.

Observations on the West of England Mining Region. By J. H. COLLINS. Wm. Brendon & Son, Ltd., Plymouth, 1912, 683 pp. Vol. 14, Trans. Royal Geol. Soc. Cornwall.

A unified treatment of the economic geology of Cornwall and Devon, bringing together a large amount of information concerning the geology, production, and history of the mines of the region.

Preliminary Report on the Economic Geology of the Hartford Quadrangle. By JAMES H. GARDNER. Bull. Kentucky Geol. Survey No. 20, 1912, pp. 1–25.

The mineral resources are coal, iron ore (as yet undeveloped), clay and cement materials. It is recommended that a test well for oil and gas be put down to a depth of at least 2,000 feet.

GENERAL.

An Experimental Contribution to the Question of the Depth of the Zone of Flow in the Earth's Crust. By FRANK D. ADAMS. Jour. Geol., Vol. 20, 1912, pp. 97–118.

The investigation has an important bearing on the question concerning the depth to which mineral deposits may extend in the lithosphere From the strength of granite under cubic compression found experimentally and the geothermic gradient it is calculated that empty cavities may exist in granite to a depth of at least 11 miles.

UNCLASSIFIED.

A Contribution to the Geology and Mineralogy of Graves Mountain, Georgia. By T. L. WATSON and J. W. WATSON. Univ. of Virginia Pub. Bull. 7, 1912, pp. 200–221.

This area is of special interest to the mineralogist because of the association of the comparatively rare minerals, pyrophyllite, lazulite, rutile, and cyanite. U.

A Handbook of Rocks. By J. F. KEMP. D. Van Nostrand Co., New York, 1911, 272 pp.

In this fifth edition tables of the sedimentary and metamorphic rocks have been added, and additional matter regarding the recalculation of the chemical analyses of rocks has been introduced. The glossary of rock names and lithological terms has been enlarged to 86 pages and brought up to date. This feature, if no other, justifies the new edition. U.

Building and Ornamental Stones of New South Wales. By R. T. BAKER. Tech. Edu. Series, Technological Museum, No. 15, Sydney, 1909, 85 pp. U.

A New Occurrence of Carnotite. By EDGAR T. WHERRY. Am. Jour. Sci., Vol. 33, 1912, pp. 574–580.

Carnotite occurs at Mauch Chunk, Pennsylvania; the vanadium was extracted by circulating surface waters from ferromagnesian pelites of Mississippian age.

Note on a Diamantiferous Garnet-pyroxene Nodule from the Roberts Victor Mine, O. F. S. By G. S. COOSTORPHINE. Trans. Geol. Soc. South Africa, Vol. 14, 1912, pp. 71–73.

Concludes that it is most probably a direct product of the solidification of the kimberlite magma.

Petrographic Methods. By ERNST WEINSCHENK, translated by R. W. CLARK. McGraw-Hill Book Co., New York, 1912, 396 pp. U.

The Production of Fuller's Earth in 1911. By J. MIDDLETON. Advance Chapter from Mineral Resources of the United States, 1911. U. S. Geol. Survey, 1912, 7 pp.

Fuller's earth occurs in many of the southeastern and south central States. In 1911 only 13 deposits were worked, due to the small though growing market, and the inferior quality of many of the American earths. U.

The Production of Mica in 1911. By DOUGLAS B. STERRETT. Advance Chapter from Mineral Resources of the United States. U. S. Geol. Survey, 1912.

The total value of the mica produced in the United States in 1911 was $355,804 or $18,707 greater than in 1910. This mineral is mined in North Carolina, South Dakota, New Hampshire, Alabama, New Mexico, Colorado and Virginia, named in the order of the value of their output. U.

The Production of Slate in 1911. By A. T. COONS. Advance Chapter from Mineral Resources of the United States. U. S. Geol. Survey, 1912.

The output of slate in the United States in 1911 was valued at $5,728,019 or $508,740 less than in 1910. The slate producing States in 1911 were Pennsylvania, Vermont, Maine, Virginia, New York, Maryland, New Jersey, Georgia, and Arkansas, named in order of importance. U.

The Production of Talc and Soapstone in 1911. By J. S. DILLER. Advance Chapter from Mineral Resources of the U. S. for 1911. 9 pp.

Talc and soapstone are derived almost entirely from the Atlantic States where for 1911 the total production was 143,551 tons, valued at $1,646,018. U.

Sulphur, Pyrite and Sulphuric Acid in 1911. By W. C. PHALEN. Advance Chapter from Mineral Resources of the U. S. U. S. Geol. Survey, 1912.

Louisiana, Utah, and Wyoming were the principal sulphur producing States in 1911, the output being valued at $4,787,049. The production of pyrite, which is used principally in the acid industry, was valued at $1,162,261 in 1911. U.

SCIENTIFIC NOTES AND NEWS[1]

THE GEOLOGICAL SOCIETY OF AMERICA will hold its Twenty-fifth Annual Meeting at New Haven, Connecticut, on the 28th, 29th, 30th and 31st of December, 1912. The society meets at Yale University on the invitation of the university. The meetings will be held in the university buildings. The unsatisfactory nature of the hotel accommodations in New Haven has heretofore prevented the society from holding its annual meeting in that city. The erection of the new Taft Hotel has, however, placed at the disposal of conventions admirable accommodations and the members of the society will probably find the city a comfortable place for meeting.

A MEETING of the section of Geology and Mineralogy of the New York Academy of Sciences was held in New York on Monday, October 7, at the American Museum of Natural History. Dr. George H. Girty presented a paper on the "Geologic Age of the Bedford Shale of Ohio"; Dr. A. A. Julien, on the "Genesis of the Apatite Veins of the Grenville Formations"; Professor Douglas W. Johnson on "The Westward Trip of the Transcontinental Excursion of the American Geographical Society"; Dr. George F. Kunz on "A Remarkable Find of Rubellite and Kunzite in the Pegmatites at Palo, California."

MR. V. H. HUGHES, E.M., has been appointed assistant state geologist of Missouri.

MR. HENRY LEIGHTON, of the University of Pittsburgh, spent the past summer investigating kaolins and other mineral deposits in the southern states.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

MR. RUSSELL T. CORNELL announces that he has opened offices at 45 Cedar Street, New York City.

ONE OF THE UNPLEASANT consequences of the present political situation has been the diversion of the attention of Congress from the internal affairs of government. This resulted during the past summer in the delay in the passage of appropriations for nearly all of the government departments. The United States Geological Survey suffered perhaps to a greater degree than any of the other branches of the government service, because their field work for the summer needed to be planned some time in advance of the actual conduct of the work. The uncertainty attending the appropriations made the completion of plans impossible and so delayed the sending of parties into the field that the summer was nearly spent before much of the work could be undertaken. The result of this has been that during the past year the Geological Survey has been able to accomplish but a small percentage of the work outlined for the year.

The following represent the items which were finally appropriated for the fiscal year ending June 30, 1913:

Topographic surveys	$350,000
Geologic surveys	300,000
Mineral resources of Alaska	90,000
Mineral resources of the United States	75,000
Chemical and physical researches	40,000
Geological maps of the United States	110,000
Gaging streams, etc.	150,000
Surveying national forests	75,000

The bill also appropriates $145,000 for printing and binding Survey reports, to be expended by the public printer. An item of popular interest included in the allotment for chemical and physical researches is that of $20,000 to enable the Geological Survey to continue its search for potash.

STEPHEN TABER, A.B. (Stanford, '06), Ph.D. (Virginia, '12), for the past three years assistant geologist on the Virginia Geological Survey and instructor in geology in the university, has been elected to the chair of geology in the University of South Carolina.

PROFESSOR HERBERT E. GREGORY, head of the department of geology in Yale University, has sailed for Peru to join the Yale Peruvian expedition under Professor Hiram Bingham.

PROFESSOR ROLLIN D. SALISBURY, head of the department of geography and dean of the Ogden Graduate School of Science in the University of Chicago, has been granted leave of absence during the autumn quarter for the purpose of scientific investigations in South America. Professor Salisbury, in company with Mr. Bailey Willis, of the United States Geological Survey, sailed from New York on August 10 for Panama, whence they cross the Isthmus and go down the west coast of South America as far as Valparaiso, Chile. A few days will be spent on the west side of the Andes, with a possible trip southward as far as the railroad will carry them in Chile, and the party will then cross the range by the Trans-Andean Railway, going into northern Argentina and then down to Buenos Aires. During October, Professor Salisbury intends to camp in Patagonia at Lake Nahuel Haupi in the eastern Andes in latitude 41°. On his return he expects to stop at Rio de Janeiro and go back into the interior from that point to the great iron deposits of Brazil.

MR. E. R. GARRETT, of the University of Oklahoma and the Oklahoma Geological Survey, has been appointed assistant in mineralogy at Northwestern University.

MR. E. W. PARKER, of the United States Geological Survey, delivered an address on October 15 before the Mechanical Engineering Society of Yale University, New Haven, Conn.

A MEETING of the American Institute of Mining Engineers was held on October 7 at the offices of the Institute in New York City. The meeting was largely devoted to the discussion of the question of an increase in the annual dues. This question has been agitated by the members of the institute for some time past, and there has been a rather sharp division into two groups of men holding divergent opinions. One group has maintained that it will be unnecessary to increase the dues; the other that the

institute is seriously in need of money and that such an increase is absolutely essential.

THE 103D MEETING of the American Institute of Mining Engineers is to be held at Cleveland, Ohio, beginning Monday evening, October 28, 1912. The institute's headquarters will be established at the Statler Hotel where a bureau of information will be maintained. The following provisional program is announced by the secretary of the institute:

Monday, October 28, 1912.

Afternoon: Registration at Headquarters, Statler Hotel.

8.15 p.m.: Informal social meeting at Headquarters.

Tuesday, October 29, 1912.

10.00 a.m. Technical Session,
2.00 p.m. Technical Session,
Evening: Informal smoker and popular addresses,
} Hotel Statler

Wednesday, October 30, 1912.

10.00 a.m. Technical Session at Statler Hotel.

Afternoon: Trip.

7.30 p.m.: Subscription Banquet, members and guests, including ladies.

Thursday, October 31, 1912.

10.00 a.m.: Technical Session at Case School of Applied Science.

Afternoon: Trip.

Evening: Unassigned.

The following papers which are of interest to the readers of ECONOMIC GEOLOGY will be presented at this meeting:

Cuyuna Iron-Ore Range, by Walter A. Barrows, Jr., Duluth, Minn., and Carl Zapffe, Brainerd, Minn.

An Investigation into the Relations existing between Hardness as measured by the Brinell and Scleroscope Methods and Depth of Carbonization upon Different Kinds of Steel Hardened under Different Conditions, by Mark A. Ammon, Cleveland, Ohio.

The St. Helens Mining District, Skamania, Washington, by Horace V. Winchell, Minneapolis, Minn.

A Titaniferous Iron-Ore Deposit in Boulder County, Colorado, by E. P. Jennings, Salt Lake City, Utah.

Our National Resources and our Federal Government, by R. W. Raymond, New York City.

The Ta-yeh Iron-Ore Deposits, Hu-pei Province, China, by C. M. Weld, Lowmoor, Va.

Clinton Iron-Ore Deposits in Kentucky and Tennessee, by S. Whinery, New York City.

Gold in Eocene Deposits, Texas, by E. T. Dumble, Houston, Texas.

FREDERICK G. CLAPP, of the Associated Geological Engineers, Boston and Pittsburgh, spent a part of September and October in Ontario and Quebec in connection with a general investigation of the oil and gas fields of Canada for the Canadian Department of Mines.

D. D. CAIRNES, of the Canadian Geological Survey, returned to Ottawa the last week in September, and reports having completed that portion of the international geological work along the 141st meridian (the Yukon-Alaska boundary) which had been undertaken by the Canadian government, the United States and Canadian geological surveys having agreed to map the geology along the boundary line from Yukon river to the Arctic Ocean, a distance of about 350 miles. This work was commenced in the spring of 1911, and by the terms of the agreement, the United States and Canadian geologists worked to the north and south respectively of Porcupine river, each extending their investigations at least 2 miles east and west of the boundary line. This work not only gives a geological section at that longitude through the northern half of the Yukon Plateau, the entire Rocky Mountain, and the Arctic Slope physiographic provinces, but should also assist materially in correlating the geology of Alaska with that of Yukon and British Columbia.